SBIR Phase II

IMAGING IR SPECTROMETER

Final Report
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Chief, Procurement Branch
M/S 180-805
Contract NAS7-1029

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PROJECT SUMMARY

The Phase II research objective was to design, fabricate and test a prototype Multichannel Imaging Spectrometer for use on groundbased astronomical telescopes. Specifications for the instrument included simultaneous operation at all channels in the spectral region $\lambda = 1.0$ to $2.5\ \mu m$ at a spectral resolution ($\Delta\lambda/\lambda$) of 1% and with a noise equivalent power (NEP) of 10^{-16} W/Hz using state-of-the-art two dimensional infrared detector arrays. Additional specifications required that the instrument be small, transportable, capable of remote operation and provide an innovative optical design to permit operation at a field of view (FOV) of 0.5 arcseconds/pixel in a mapping mode and 5 arcseconds per pixel in a spot mode.

The research effort was divided into several stages. The first stage was to review the specifications and to develop an engineering design, with associated shop drawings, for the spectrometer optical, electronic and software systems. The second stage of development was to build and test each subsystem and subassembly. The major subsystems are (1) the spectrometer mechanical housing (dewar) which provides environmental and mechanical stability and support for the optical bench, (2) the electronics and electronic interfaces which provide the two-way communication with the detector and internal dewar operations, (3) the computer and interfaces which provide the hardware for data storage, control and remote operation and (4) the software and software interfaces which provide the operating environment for controlling the spectrometer and preforming analysis of the data. The research was performed primarily at the facilities of SETS, Inc., although the machining, mechanical design and fabrication of certain specialized optical and electronic components were accomplished at other facilities either under contract or under our direction.

The major research result is that a low cost multichannel infrared spectrometer, or IR imaging spectrometer operating across the spectral region $\lambda = 1.0$ to $2.5\ \mu m$ and meeting the specifications of the Phase I proposal is possible and practical. A prototype IR imaging spectrometer was successfully designed, fabricated and tested in the laboratory. The instrument as fabricated operates over the wavelength interval of 0.9 to 2.6 μm with an average spectral resolution of 1%. The 128 x 128 Rockwell HgCdTe array performs well within the NEP specifications. A user friendly and versatile software program (written in C) with pull-down menus controls the operation of the spectrometer.

Other significant research findings are as follows: (1) concave holographic gratings can be used in infrared imaging spectrometer instruments and can be designed to operate over more than one spectral octave on the same focal plane with the addition of a "step function" order sorting filter; (2) concave holographic gratings must have the grating etched into their glass substrate for operation at liquid nitrogen temperature; (3) the use of electronic "taxi" communication connections between the computer and the spectrometer allows for a significant distance between the spectrometer housing and the computer controller; (4) commercially available (at present) two dimensional infrared detectors can be effective in this type of imaging spectrometer, and (5) the optical design developed under this research considerably reduced the size of the instrument and has significant commercial applications.

The commercial applications span private sector and government agencies. The unique optical design has captured the attention of several agencies for possible use in space-based instrumentation particularly for planetary missions where small, lightweight, low power and optically efficient spectrometers are required. The private sector is interested in small lightweight spectrometers for commercial applications in remote sensing from both space and aircraft platforms. Commercial interest in the optical design has prompted SETS, Inc., to design the VIRIS™ line of imaging spectrometers which operate from 0.4 to 5.0 μm.

I. INTRODUCTION

This document is the final report by the Technical Services Division of SETS, Inc., for Phase II in the development of a prototype imaging spectrometer for use on a groundbased telescope. This research was carried out under the auspices of the Small Business Innovative Research program of the National Aeronautics and Space Administration under contract NAS7-1029.

The prototype imaging spectrometer described here was designed and developed in two steps: Phase I (Contract NAS7 87 26) which dealt with research carried out in response to NASA SBIR Subtopic 08.27, Multichannel Infrared Spectrometer and Phase II (1986 solicitation) which dealt with the actual construction of a prototype imaging spectrometer system performed in response to a Phase II award.

A. Phase I Research and Results

The Phase I research confirmed that a spectrometer capable of sampling simultaneously the spectral range 1.0 to 2.5 μm at 1% spectral resolution with a NEP of 10^{-16} W/Hz was feasible. It was found that the opportunity to develop the spectrometer would provide opportunities for research and development in the areas of infrared detector arrays, innovative optical designs and microelectronics. Phase I work included:

- a review of existing spectrometer designs.
- an identification and qualification of suitable two dimensional array detectors.
- a review and modification of optical designs to permit maximum throughput.
- a model of thermal emission from the spectrometer.
- a exploratory review of cooling options for the focal plane and optical bench.
- a conceptual design of the analog and digital control electronics.
- research into remote operation.
- a conceptual design of the mechanical structure of the instrument.
- a refined market research.

Phase I results indicated:

- that the instrument was feasible.
- that an operating prototype could be constructed under the schedule and cost constraints of Phase II.
- that a small and growing market exists for imaging spectromters both in the commerical and government environments.

The details of the Phase I research are reported in the Phase I Final Report, dated August 1987.

B. Phase II Technical Objectives

The overall objective of Phase II was to design, fabricate and test a prototype of a multi-channel infrared imaging spectrometer. To reach this goal, the project was divided into four stages of development, each with its own objectives and schedule.

The objective of the first stage was to review the specifications and to develop an engineering design with shop drawings for the spectrometer. Guidelines and specifications for each of

the major components of the spectrometer were then developed. From these guidelines the optical configuration was reviewed and used to define the mechanical drawings for the spectrometer.

The second phase of the development was to build and test each of the individual subsystems and subassemblies which make up the spectrometer. These subsystems are (1) the spectrometer housing (dewar), (2) the electronics and electronic interfaces, (3) the computer and computer interfaces, and (4) the software and operations. Additionally, major subassemblies include the optical bench (grating), the detector array, the mechanical feedthroughs, the guiding camera and the aperture assembly. The major subsystem and subassemblies that were targeted for special attention were the detector, the grating, the spectrometer housing, and the computer system.

C. Potential Commercial Applications

The development of this prototype imaging spectrometer has generated considerable interest among both private sector and government agencies. The optical design (described below) using holographic optics has captured the attention of the Jet Propulsion Laboratory for possible use in planetary mission instruments; several federal agencies interested in small, lightweight, low power imaging spectrometer systems, and the private sector which is interested in small, lightweight, low power imaging spectrometers for use in terrestrial remote sensing from either aircraft or spaceborne platforms.

The commercial interest in imaging spectrometers based upon our optical design has prompted SETS, Inc., to produce the VIRIS™ line of imaging spectrometer systems which operate from 0.4 to 5.0 μm.

II DETAILED PROJECT REVIEW

This section describes in detail the design, construction, testing and operation of the prototype imaging spectrometer developed under the Phase II effort.

A. General Theory of Operation and Application

An imaging spectrometer produces a series of images of a scene (astronomical, terrestrial, medical, etc.) at a number of wavelengths. Each scene characterizes the photometric contrast in the scene at a particular wavelength so that spectral contrast at a variety of wavelengths can be coregistered and studied. These scenes can be developed either by scanning through wavelengths as the two spatial dimensions of the scene are held constant or by scanning through one spatial dimension of the scene and holding the other spatial dimension and the sampled wavelengths constant.

The instrument developed here produces 128 scenes at 128 different wavelengths between the wavelengths of approximately 1.0 and 2.5 μm by producing a spectrally dispersed image of a slit on a two dimensional array. Scanning the slit in the orthogonal spatial dimension produces a two dimensional spatial scene at 128 wavelengths. This data set is commonly called an "image cube" which has two spatial dimensions (a picture) and one spectral dimension (the photometric contrast as a function of wavelength).

The prototype spectrometer is designed for use at an astronomical telescope, although it is not limited to such. The light from an astronomical scene (the moon for example) is imaged onto the slit of the spectrometer. The slit is reimaged by way of a holographic grating onto the

two dimensional detector. The grating produces spectrally dispersed images of the slit, or in essence, 128 images of the slit, each at a different wavelength. A reading of the detector (a frame) yields a digital measure of the intensity as a function of wavelength along 128 points on the slit. The telescope is then stepped in a direction orthogonal to the length of the slit to a position just adjacent to the first frame. Additional readings are taken until a two dimensional spatial image is developed.

The action of dispersing and recording the spectral/spatial image is performed by the optical design of the spectrometer. The spectrometer is composed of four major subsystems: (1) the spectrometer housing (dewar), (2) the electronics and electronic interfaces, (3) the computer and computer interfaces, and (4) the software and operations. These subsystem were required to meet the following specifications and operating environments:

Spectrometer housing: The spectrometer housing was required to withstand the mechanical loads of normal astronomical equipment. Three important criteria must be met: (a) maintain vacuum over the course of many days, (b) permit operation of an optical bench in a cryogenic environment, (c) be designed to maintain a minimum of thermal loads and optical light leaks, and (d) maintain mechanical durability in the course of normal operation.

Criteria (a) and (b) are required for the operation of the two dimensional detector described below. Criteria (c) is necessary to reduce the cryogenic requirements and the need for baffling internal to the dewar. Criteria (d) is normal to most astronomical equipment. It is to be shipped, handled, and placed on the baseplate of a telescope which will move the device to a variety of angles and positions during the course of observations. This mechanical housing must provide a stable housing for the internal optical components which must remain optically aligned.

Electronics and Electronic Interfaces: The electronics and electronic interfaces are important aspects of the spectrometer since they provide the communication for operating and acquiring data from the spectrometer housing. Two dimensional array detectors produce a prodigious amount of data that must be handled rapidly and accurately. The spectrometer housing is designed to operate at the baseplate of a telescope generally separated from the computer and other control electronics by several tens of meters. The transfer of data between the data acquisition and data storage subsystems requires rapid electronic communications protocol. The spectrometer housing and the electronics have similar mechanical environments.

Computer and Computer Interfaces: The computer provides control and data storage for the spectrometer. The computer must be capable of rapid operation, and data acquisition and storage. Additionally, the option of remote operation must be maintained.

Software and operation: The computer software must be useable by those not familiar with programming and computer operations. Also, the computer software must provide enough processing capability to allow the operator to preview the data obtained by the spectrometer. Although the mechanical constraints of the computer are not as severe as those of the spectrometer housing and the electronics, the user is quite intolerant of balky programs.

B. Mechanical Subsystem

1. Mechanical Design

The mechanical design of the spectrometer has been guided by experience gained from existing groundbased astronomical instruments with cryogenically cooled (liquid

nitrogen, LN2) optical benches and focal planes. These instruments require that the spectrometer optical bench be housed in a mechanically strong vacuum dewar with numerous optical, electrical and mechanical feedthrus capable of holding, in spite of repeated handling and motion, a high vacuum for periods of at least days and preferably months. The mechanical housing must be constructed so that thermal loads on the optical bench, and in particular the focal plane, are minimized to optimize the single-fill hold time of the cryogenic reservoir. All optical windows must be designed to minimize the amount of scattered light (both visible and thermal) that enters the instrument and reaches the optical bench.

The mechanical system layout of the spectrometer is shown in the mechanical drawing GENASSY-100. The major mechanical subsystems of the spectrometer are (a) spectrometer housing (dewar), (b) the two cryogenic reservoirs, (c) the optical bench, (d) the optical bench heat shield, (e) the selectable aperture subassembly, (f) the two mechanical feedthrus, and (h) the evacuation valve.

The spectrometer housing is made from a solid block of aluminum hollowed out to form four sides of the box, with two end plates, which form the other two sides of the box. This configuration is a compromise, minimizing number of major vacuum tight seals (two), while still allowing great flexibility for access to the spectrometer optical bench and cryogenic reservoirs.

Two copper liquid nitrogen reservoirs and associated fill and vent tubes permit up-looking and side-looking operation at the telescopes. Each reservoir, after initial cool-down, provides a hold time of about 11 hours. (See Section II.F.2 for a detailed discussion of hold time tests.) The solid copper optical bench is situated in direct contact with the two liquid nitrogen reservoirs. The locations of the optical components and their associated fine adjustments are keyed to the requirements of the holographic grating and the compact system design. Factors such as the thermal coefficients of the optical bench and the mounts for each element have been considered, and repeated cycling of ambient to liquid nitrogen temperature show the stability of the optical path as a result of these design considerations. All the optical elements (except necessarily for the windows and part of the CCD guide camera transfer optics) are cooled to the same temperature as the detector. This dramatically reduces the thermal background due to the optical elements.

To further cut down on thermal background from the dewar walls, the optical bench is enclosed by a copper cold heat shield. The copper cold shield sits on top of the optical bench, and therefore is cooled by the liquid nitrogen reservoirs. A copper cover sits on top of the cold shield walls and completes the cold shielding of the optical bench. The only two ports in the cold shield are the spectrometer entrance port and the guide camera exit port. To block off radiation from the camera exit port, a baffling screen is installed in place. (See mechanical drawing DET62-100.)

Two handcranks located outside the spectrometer enter the spectrometer housing by ferrofluidic feedthrus. One is for rotation of the aperture wheel and one is reserved for future use with a focal reducer. The aperture wheel handcrank mechanism allows the operator to pick the desired aperture. There are eight rotary positions on the aperture wheel consisting of four apertures and four blocked half-positions. The focal reducer is not installed, but a ferro-motor mount is reserved for this purpose. Motors may be installed for both the current aperture wheel and focal reducer assemblies for motorized positioning.

2. Vacuum Handling Procedure

This section describes the recommended procedure for achieving a proper vacuum in the spectrometer.

Once the spectrometer has been open to the atmosphere for several hours, after closure and He-leak checked for possible leaks, it is recommended that the spectrometer housing be pumped for at least 48 hours on a high vacuum (<= 10-6 torr) pump station to ensure removal of as much adsorbed water vapor as possible. For open periods of an hour or two, 12-hour pump-down is usually adequate. (Heating the spectrometer to an elevated temperature to accelerate purging of surface adsorbed molecules is **not** recommended, as damage to the detector will result and damage to the internal electronics and optical components is quite likely. Rockwell has not provided safe upper temperature limits for the detector.) The amount of outgassing is less the longer the system is on a high vacuum station. To help enhance the holding time with a given charge of cryogen, a "getter", consisting of a measure of activated carbon, has been attached to the inside surface of the removable lid of the radiation shield. This unit will continue to effectively cryopump residual vapors from the interior for several hours and thus will ensure maintenance of a high vacuum (assuming no leaks to atmosphere) while the unit is at liquid nitrogen temperature . When vacuum is maintained but the instrument is allowed to warm up, it is generally good practice to re-pump the spectrometer after warm-up and before the next cool-down to re-establish a good base pressure and thus retain the efficiency of the getter. During cool-down the walls may feel quite cool until the getter pumping speed is established; however, if frosting is observed, abort and check for leaks.

Filling the LN2 reservoirs with the cryogen initially is a slow process because of the rapid back-flow of gas from the boiling of the liquid as it is being introduced. Once liquid begins to collect, however, the filling proceeds rapidly. The process usually consumes about 4 litres of liquid. The volume of each of the reservoirs is about 750 ml.

The cryogen hold time is a very sensitive function of the quality of the ultimate vacuum achieved. Prior to closing-up, all surfaces which have been opened should be examined for scratches (the aluminum outer box is especially susceptible to dings and scrapes), tiny hairs and particles of dust. Any associated O-ring involved should be regreased to ensure freedom from tiny hairs and dust particles. While the lids are removed, it is recommended that they be stored wrapped in aluminum foil and that the exposed edges of the box also be so protected. When back-filling the instrument, it is recommended that dry nitrogen be used.

Clean lint-free clothes and clean gloves should be used when handling vacuum surfaces.

C. Optical Design

The instrument designed in this phase emphasizes the use of optical components representing the latest commercially available technology such as concave holographic gratings (well corrected for aberration), order-sorting step filters and a two dimensional array detector for use at IR wavelengths. A concave holographic grating was used to provide a flat focal plane and minimize aberrations. The optical components are enclosed in a vacuum coldbox and held at an operating temperature of 77° K, therefore reducing the thermal background noise. The advantages of this design are simplicity, mechanical ruggedness and low mass, all of which are important when designing a transportable instrument. The design is characterized

by a low number of optical elements, compactness, ease of alignment, state-of-the-art array detectors and optical efficiency.

1. Optical Elements

Figure I shows the final optical layout of the system. The optical components of the system are: sapphire entrance window, pellicle beamsplitter, apertures (two slits and two pinholes), transfer optics for CCD camera, glass window for CCD camera exit port, neutral density filters for the CCD camera, folding mirror, holographic concave grating and order sorting filter. The spectral transmission efficiency/reflectivity of the optical elements have been measured.

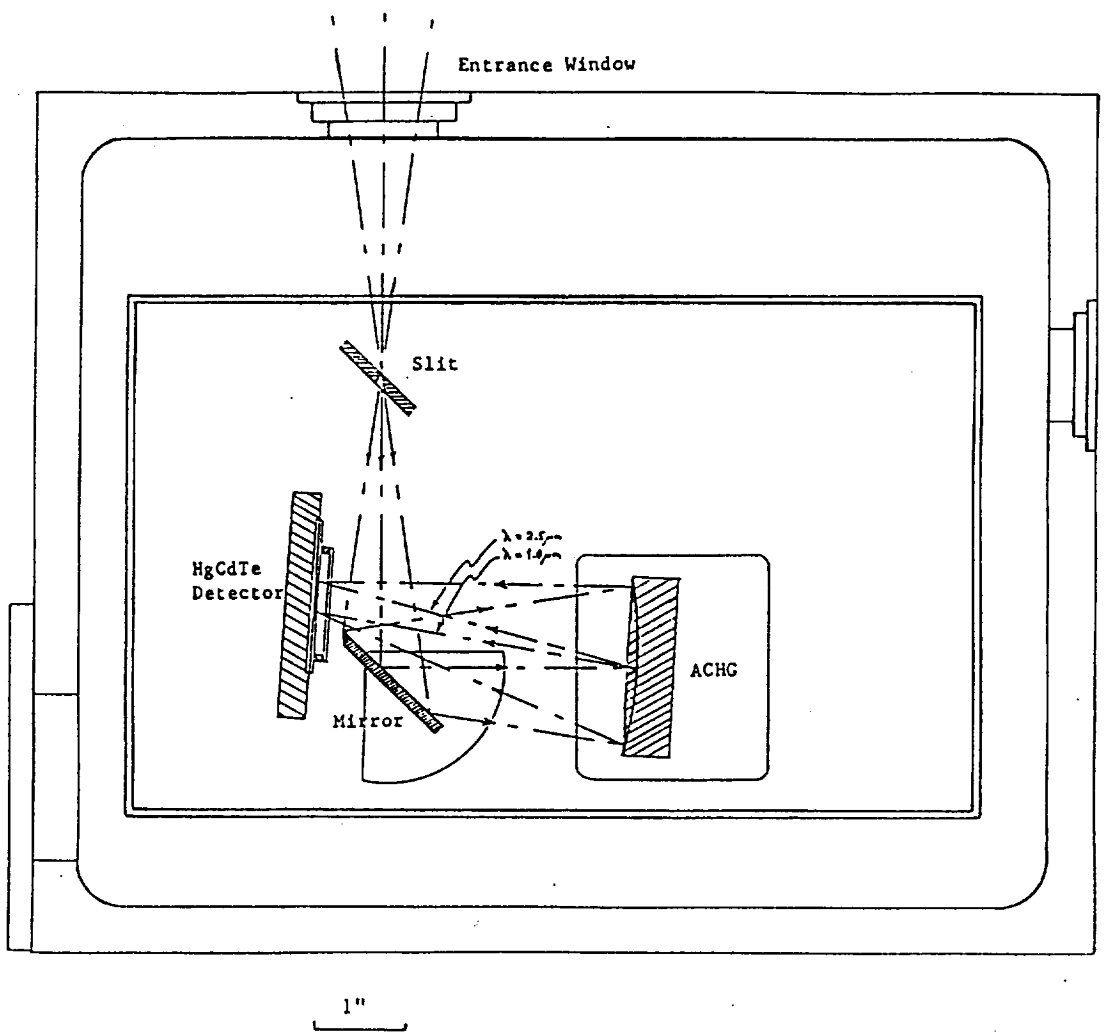


Figure I. Optical System Layout

The measured transmittance/reflectance are as expected. They are plotted and have been included with the Prototype Instrument Package. The specifications for each component are described below.

Sapphire Entrance Window: The synthetic sapphire window is the entrance port of the spectrometer. The window allows light to enter the spectrometer which is maintained under vacuum.

Manufacturer:	Melles Griot
Part Number:	02 WSA 012
Material:	Anisotropic crystalline synthetic sapphire
Transmission:	~ 85% from 1-2.5 µm (see Optics Guide 4 p. 13-2)
Diameter:	40 mm ± 0.25 mm
Thickness:	2 mm ± 0.1 mm
Cosmetic Surface Quality:	80-50
Flatness:	1λ per 25 mm at 632.8 nm over 90% of aperture
Parallelism:	3 arc min.
Birefringence (n_o - n_c):	0.008 for visible light in direction orthogonal to the optical axis
Stress Birefringence Coefficient:	0.1 fringe per mm thickness at 632.8 nm and 2.43 kilograms per cm^2

Pellicle Beamsplitter: A pellicle beamsplitter is mounted in front of one of the two slit apertures. The pellicle transmits 90% and reflects 10% of the incident light without producing interference fringes. The reflected light is imaged onto the CCD guide camera so that the position in the slit of the object under study can be monitored continuously.

Manufacturer:	Melles Griot
Part Number:	03BPL001/01
Material:	Select optical grade nitrocellulose
Index of Refraction (n_d):	1.5
Coating:	/01 (see Optics Guide 4 p. 13-11) ~ 85 - 90% transmission from 1-2.5 µm, ~ 40 - 80% transmission in visible region
Optical Diameter:	34.9 mm
Clear Aperture:	25.4 mm
Thickness:	5 µm
Thickness Uniformity:	2λ per 25 mm
Cosmetic Surface Quality:	40-20
Temperature Range:	-40°C to + 125°C
Humidity Range:	≤ 95% relative humidity
Frame:	Hard aluminum alloy, black anodized
Frame Thickness:	4.8 mm
Special Notes:	Very sensitive to acoustical disturbances, should be isolated from severe acoustical noise. Pellicle surfaces must not be touched. Clean ONLY with a gentle flow of clean, dry air.

Apertures: The entrance aperture is positioned on a flat reflective surface angled 45° to the incident beam. Four aperture positions are available on the rotating slit mechanism. The

four apertures are: (a) dull surfaced slit with pellicle beamsplitter, (b) bright surfaced slit, (c) dull pinhole, and (d) bright pinhole. The slits are for the mapping mode, and the pinholes are for the point mode. Light passing through the aperture in use enters the optical path of the spectrometer for dispersion and detection. Light incident on the aperture surrounding the slit/pinhole is reflected to a CCD guide camera.

Manufacturer:	Buckbee-Mears
Material:	Bi-Metal, 0.005" copper substrate with bright nickel plating of 0.0005". Nickel surface determines the apertures of slits and pinholes.
Diameter:	1.062" ± 0.001"
Clear Aperture:	0.9680"± 0.0005"
Slit Size:	11 mm ± 0.1 mm x 133 μm ± 2 μm
Pinhole Diameter:	(a) 140 μm bright surface (b) 140 μm dull surface
Surface Quality:	Not specified. Hand polished with metal polish (Brasso) to form reflective surface on nickel side.

Together with the foreoptics, the size of the spectrometer aperture determines the field of view of the system. A 40 inch (1.016 mm) telescope operated at f/35 has a plate scale of 5.8 arcsecond/mm. The effective size of the slit aperture oriented at 45° is (taking into account the thickness of the slit) 11 mm x 107 μm, which gives a field of view of 64 arcsec x 0.62 arcsec. The effective pinhole aperture diameter is 112 μm along the 45° tilted spectral direction, and 140 μm along the spatial direction, which gives a field of view of 0.65 arcsec x 0.81 arcsec.

The size of the apertures has been verified to conform to the manufacturer's specifications. The aperture sizes were measured by observing the Fraunhofer diffraction patterns of the slit and the pinhole apertures.

Transfer Optics for CCD Guide Camera: The transfer optics for the CCD guide camera consist of two lenses, one inside the spectrometer and one outside the spectrometer. The two lens system images the spectrometer aperture onto the CCD camera. This image is displayed on the camera monitor. The specifications for the two lenses are listed below, and Figure II shows the notation system used. Table I contains the distances between the components, and Figure III is the diagram of the transfer optics system.

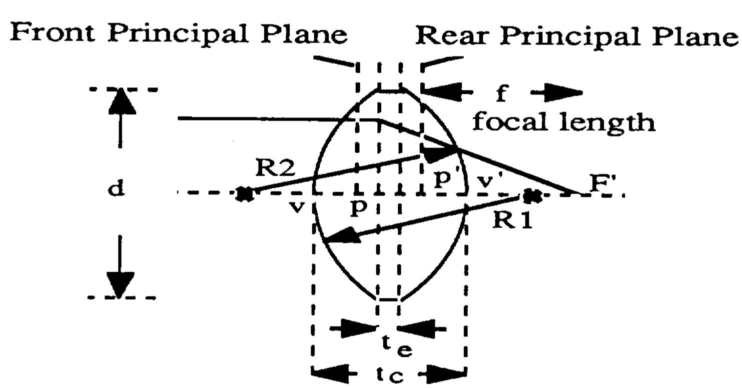


Figure II. Notation for Lens.

Lens 1: Located inside the spectrometer dewar
Biconvex crown glass lens
$f = 75$ mm ± 0.5%
$d = 50$ mm ± 0.5 mm
$tc = 10.9$ mm ± 0.5 mm
$te = 2.5$ mm
$R1 = R2 = 76.8$ mm
$vp = 3.4$ mm
$pp' = 4.1$ mm
Concentricity < 0.15 mm
Cosmetic Surface Quality: 80-50
Ealing Electro-optics #30-8130

Lens 2: Located outside the spectrometer dewar
Plano-aspheric condenser optical crown lens
$f = 34.5$ mm ± 7%
$d = 38$ mm ± 0.4 mm
$tc = 12$ mm ± 7%
$R1 = 18$ mm
$R2 = \infty$
$vp = 0$
$pp' = 4.1$ mm
Cosmetic Surface Quality: 80-50
Maximum Service Temperature: 177°C
Melles Griot #01LAG012

Table I. Distances Between Components of CCD Camera Transfer Optics

Element	Distance to next element	Marginal ray height
Spectrometer Aperture	86.4 mm	0
Lens 1, v1 (front vertex)	166.8 mm	12.8 mm
Lens 2, v2 (front vertex)	35.0 mm	8.3 mm
CCD	0	0

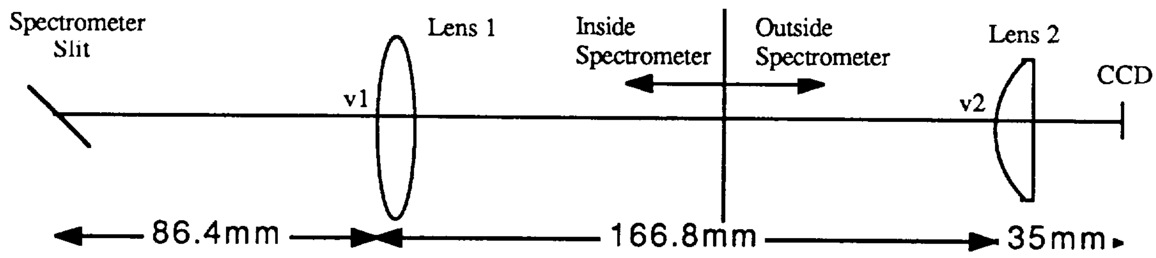


Figure III. Layout of the CCD Camera Transfer Optics.

Exit Window for CCD Camera Transfer Optics: The glass window is the exit port for light imaged from the spectrometer aperture onto the CCD guide camera. The window is needed because the camera is located outside the evacuated spectrometer..

Manufacturer:	Edmund Scientific Company
Part number:	N30,582
Material:	Sloat optical glass
Diameter:	34 mm
Thickness:	3 mm

Neutral Density Filters: A set of neutral density filters along with a filter wheel is provided for the CCD guide camera. The filter wheel assembly is located outside the spectrometer, between the camera and the spectrometer.

Manufacturer:	Oriel Corporation
Part Numbers:	50271, 50272, 50273, 50274, 50275, 50281, 50283, 50285
Material:	A thin metallic coating on a single glass substrate for ND 0.1 - 2.0, and two metallic coatings sandwiched between two layers of glass with edges cemented for ND 3.0 - 4.0.
Neutral Densities:	ND = 0.1, 0.2, 0.3, 0.4, 0.5, 1.0, 2.0, & 4.0. The average density from 400 - 700 nm is within 10% of the nominal density. Density reading from 400 - 700 nm is within 5% of the average density (10% for 0.1 and 0.2 D filters).
Diameter:	1 inch
Thickness:	1/16" - 1/8"
Notes:	The coatings on the filter are supposedly corrosion, scratch, and abrasion resistant. The density data for each filter is supplied at 50 nm increments from 400 - 1000 nm along with an average visible density. The data is contained in the neutral density filter box.

The following filters are currently installed in the filter wheel:

Filter Position	Filter ND
1	none
2	none
3	1
4	2
5	4

Folding Mirror: The folding mirror directs light from the spectrometer aperture onto the grating. The purpose of the mirror is to fold the optical axis to allow for compact design of the spectrometer and small angle between the incoming beam and the dispersed beam on the grating (which reduces off-axis aberrations in the optical system).

Manufacturer:	Janos Technology, Inc.
Part Number:	A1510-272
Material:	Silicon, single crystal
Coating:	Protected Silver (see Janos catalog, 1989, p. 164) ~ 98% reflectance from 1-2.5 μm
Optical Diameter:	38.1 mm
Clear Aperture:	30.5 mm
Thickness:	4 mm
Cosmetic Surface Quality:	40-20
Flatness:	λ/40 at 10.6 μm
Parallelism:	3 min.
Special Notes:	Use the following steps in cleaning: 1. Blow off loose particles with compressed air. 2. Flush surface with spectral grade methanol or acetone. 3. If 1 and 2 don't work, soak a lens tissue with acetone and drag tissue across outside (unused) edge of mirror. Not recommended for central (used) region of mirror. Contact manufacturer for tough stains.

Grating: The incident light is dispersed by a concave holographic grating that is well corrected for aberrations over the wavelengths of interest. The object distance from the aperture to the grating is 150 mm, and the image distance from the grating to the HgCdTe detector array is 90 mm. This design allows a 100 μm slit to be imaged onto the 60 μm pixel. The grating is designed for operation in the mapping mode at f/15 through f/35 and for operation in the spot mode at f/3.5. Off-axis images in the spot mode are degraded by the fast optical system.

Manufacturer:	American Holographic, Inc.
Grating Number:	490.32
Part Number:	7399D
Material:	Pyrex, fine annealed substrate Bakelite photoresist, gold top coating
Groove Frequency, N:	51 grooves/mm
Order used, M:	-1
Radius of Curvature:	112 mm
Focal Length:	56 mm

Entrance Slit Distance:	150 mm
Angle of Incidence:	3.6°
RLD best fit:	0.219663 $e^{-0.015807\lambda}$ nm/µm
Diameter:	50 mm
Clear Aperture:	44 mm
Thickness:	12.3 mm
Cosmetic Surface Quality:	60-40 concave surface, commercial polish backside

Table II provides the ray-traced characteristics of the IR grating operated at f/35 for three points along a 10 mm long slit: center (0 mm), midpoint (2.5 mm), and end (5.0 mm). Table III provides the characteristics of the IR grating at f/3.5 for the center of the slit only. These conditions cover the range of operation of the spectrometer for both mapping and point mode. Use at other f numbers, such as f/10, would fall between these two examples.

In these tables, pixel indicates the height of the pixel (in the spatial dimension or perpendicular to the slit) and provides an idea of the image quality. The quality in the spectral dimension is given in the column labeled Band Pass. The near constant dispersion, characteristic of gratings but slightly modified by this novel approach to grating technology, indicates that the bandpass should remain constant across the focal plane. Deviations (increases in band pass) from the constant value of 121 Angstroms indicates a degradation of spectral quality due to residual, uncorrected aberrations. The final two columns compare the actual ray-traced performance (spectral resolution = l/dl) to the theoretical performance of the grating.

Table II. Grating parameters operated at f/35 (mapping mode)

	Lambda	Disp	Pixel	Eff.	Band Pass	Actual	Theor.
		(µm)	(A/mm)	(mm)	(%)	Resolution	Resolution
on slit = 0.0 mm							
	1.00	1922	0.06	100	120	83	85
	1.25	1936	0.06	100	120	104	107
	1.50	1949	0.06	100	121	124	127
	1.75	1961	0.06	100	121	145	149
	2.00	1973	0.06	100	121	165	171
	2.25	1983	0.06	100	121	186	192
	2.50	1993	0.06	100	121	207	213
on slit = 2.5 mm							
	1.00	1922	0.07	97	123	81	85
	1.25	1936	0.07	97	122	102	107
	1.50	1949	0.07	96	124	121	127
	1.75	1961	0.07	97	124	141	149
	2.00	1973	0.07	96	125	160	171
	2.25	1983	0.07	96	125	180	192
	2.50	1993	0.07	96	126	198	213
on slit = 5.0 mm							
	1.00	1922	0.08	92	128	78	85
	1.25	1936	0.08	92	129	97	107
	1.50	1949	0.08	92	131	115	127
	1.75	1961	0.09	91	132	133	149
	2.00	1973	0.09	91	134	149	171
	2.25	1983	0.09	91	135	167	192

Table III. Grating parameters operated at f/3.5 (point mode)

	Lambda	Disp	Pixel	Eff.	Band Pass	Actual	Theor.
	(µm)	(A/mm)	(mm)	(%)	(A)	Resolution	Resolution
Height on slit = 0.0 mm							
	1.00	1922	0.14	84	154	65	85
	1.25	1936	0.12	87	138	91	107
	1.50	1949	0.10	90	130	115	127
	1.75	1961	0.09	93	127	138	149
	2.00	1973	0.09	96	126	159	171
	2.25	1983	0.09	95	135	167	192
	2.50	1993	0.09	94	159	157	213

The optical design called for a average spectral resolution of 100 from 1 to 2.5 microns. We see that, except for the spectral region 1.00 to 1.25 μm, this performance is exceeded in the mapping mode. Because we can determine the MTF for every detector element, one can, in principal, deconvolve the spectral and spatial mixing and produce spectral maps at near theoretical performance. This may be warranted when operating in the point source mode.

The focal plane image at several f/#s and wavelengths have been measured in a room temperature bench top setup outside of the spectrometer. The efficiency of the grating is given in Figure IV. The grating may be upgraded by blazing or redesigned for blazing for an improvement in efficiency by a factor of approximately two. The measured spectral resolution of the grating conforms fairly well to the grating specification. However, the image quality is poor at f/3.5 – f/10. This should not affect the f/3.5 point mode since the spectral resolution at f/3.5 is still fair.

The grating delamination problem due to cold cycling is described in the SBIR 7th Quarter Report. The results are repeated here. The grating has undergone several cold cycles. After the first cold test on the grating for the spectrometer, the edge circumference of the grating coating (photoresist and top gold layer) partially flaked off. The damage is believed to have been caused by the different thermal expansion coefficients of the photoresist coating (Bakelite) from the substrate (Pyrex). The photoresist shrunk faster than the substrate when cooled; this caused portions of the photoresist to form fracture lines. The damaged portion ranges from 0 – 1 cm around the edge of the grating. After five cold tests, the loose coating (caused by the fracture lines) around the edges peeled off. However, the central portion stabilized and there does not appear to be significant degradation further into the central region. The grating is still usable as is for larger f/#s (f/# ≥ f/10).

Jonathan Gradie has visited the grating manufacturer with the damaged grating. The grating manufacturer offered several possible solutions. The most promising is to ion etch the grating (including the hologram) onto the substrate itself, foregoing the photoresist layer. The grating manufacturer can remake the grating with the grating pattern etched onto the substrate as an upgrade option.

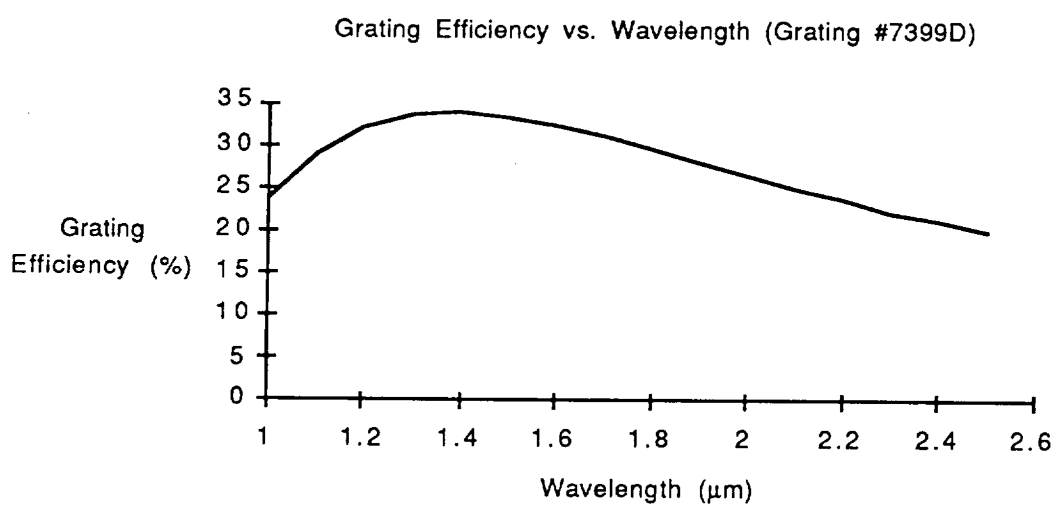


Figure IV Efficiency of Grating.

Order Sorting Long Wave Pass Filter: Covering the detector array is an order sorting filter which rejects the second and higher orders of wavelengths shorter than 1.6 μm from incidence on the region of the detector where the first order of 1.6 – 2.62 μm falls. In the above region, the filter rejects light of wavelengths shorter than 1.6 μm.

Manufacturer:	Corion
Part Number:	RL-1500-F
Material:	Infrasil substrate (as of 11/89, substrate changed to silicon, exclusively, infrasil available at $5000 for 20 pieces only)
Coating:	Probably aluminum oxide Coating quality per MIL-O-13810B, 40-20 Coating hardness and adhesion per MIL-M-13508C
Minimum Average Transmittance:	75% (see Corion catalog p. 49)
Minimum Spectral Range:	1.7 – 3.4 μm
Cut-on Wavelength:	1.5 μm ± 2.5%
Slope:	≤ 6%
Rejection:	≤ 0.1% from 1.35 μm
Optical Diameter:	25.4 mm
Minimum Clear Aperture:	22.4 mm
Thickness:	1 mm
Surface Quality:	Per MIL-O-13830B, 80-50
Operating Temperature:	-50°C to +150°C
Humidity:	Per MIL-C-675A
Special Notes:	Clean with spectral grade methanol and then acetone.
Etching of Step Filter:	Laser etched. Laser spot diameter ≈ 50 μm.

The order sorting filter requires special fabrication since it is not a stock item in optical supply companies. We have fabricated and tested a prototype order sorting filter. The filter is made from a commercial highpass filter etched to produce the spatial step-filter. The original filter had half of its coating etched off such that the filter consists of two half moon sides, one half coated and one half uncoated. Because the filter is the first one made, the initial experimental process left several uneven marks on the clear half (of 50 μm spot size due to the laser source employed). This is evident when the system is set for a long integration time. However, with flatfield calibration, this should not present a problem. Spectral response of the order sorting filter was measured before and after the filter fabrication, and the results are as desired. After the filter is installed in the spectrometer, the second order diffractions, evident without the filter, are observed to be successfully blocked out. Furthermore, the modified filter does not seem to significantly affect the intensity of the first order signals.

2. Optical Alignment

This section describes the spectrometer optical alignment procedure. The optical alignment may be performed in several ways. The sequence used to align the spectrometer is by starting at the spectrometer aperture and aligning each optical element encountered along the beam path. Thus, the majority of the elements may be aligned before the detector is installed, and reducing the number of times the detector must be handled. This cuts down the risk in handling the detector. The following steps are used to optically align the spectrometer.

a. A Helium Neon laser is used for centering the optical elements. The laser beam is first centered on the reflective spectrometer pinhole aperture. To ensure that the beam is centered along the optical axis, the laser is moved back and forth on a translation stage along the optical axis (z direction) while making sure that the beam stays at the same spot on the aperture wheel.

b. The folding mirror has two angular degrees of freedom: rotation of angles ϕ and ψ. (See Figure V for the coordinate system layout.) Angle ϕ is adjusted such that the mirror stands perpendicular to the optical bench, parallel to the y axis. This is accomplished by passing the HeNe beam through the slit aperture and adjusting the reflected beam off the mirror to the same height as the scattered beam off the front surface of the aperture. (The slit aperture scatters the incident laser beam around the walls of the cold shield in a horizontal line at the same height as the incident beam.) Adjustment of angle ψ of the mirror is described in step e.

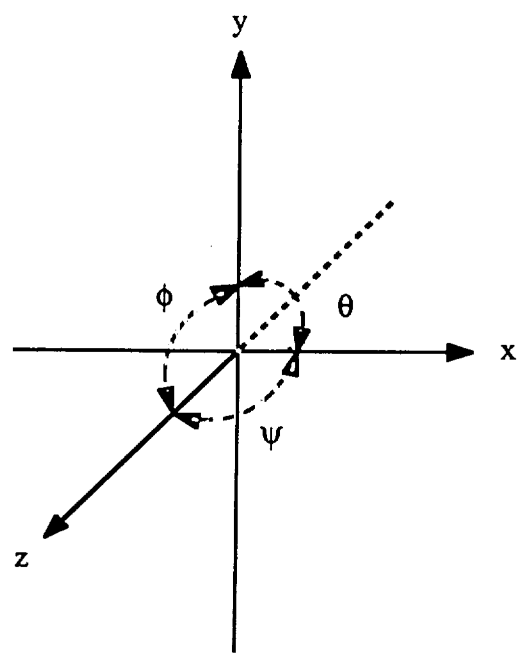


Figure V. Coordinate system for optical alignment. Z is the optical axis.

c. The grating has two rotational adjustments: angles θ and ψ. Angle θ is adjusted such that the diffracted orders are horizontal across the detector array. This is done by first mounting the grating on the optical bench and then rotating the grating such that the grating orders are parallel to the diffracted beam (off the spectrometer aperture) horizontally around the cold shield walls. Use the pinhole aperture first, and then check with the slit aperture. As a final check, shine a flashlight through the spectrometer entrance window and check qualitatively the straightness of the visible lines.

d. The height (y location) of the grating is adjusted such that the grating center coincides vertically with the optical axis. This is achieved by inserting shims between the grating mount and grating base mount until the grating orders are on top of the aperture diffracted beam. As a second check, diffracted orders from the grating should be at the same height as the incident beam spot.

e. Angle ψ of the mirror is rotated such that the incident beam centers horizontally on the grating. The easiest way to do this is to draw the outline of the grating on a piece of lens tissue and mark the center spot of the grating on the lens tissue. Rotate the mirror so that the incident beam is centered on the center marked spot when the tissue is held directlyt in front of the grating. Although this method is not very precise, the accuracy is good enough for operation of the spectrometer.

f. Angle ψ of the grating adjusts the spectral range incident on the detector. To select the proper wavelength region, the detector needs to be mounted in place. Be sure to properly ground oneself and the detector before starting this step. See Section II.D.1.a Care and Handling of the Detector Array. To set the detector plane parallel to the image plane, use the HeNe laser source and line up the reflection of the image spot off the detector surface with the reflection off the order sorting filter by rotating the detector clockwise or counterclockwise. A big bonus of the spectrometer is that the detector operates at some level when warm. To achieve room temperature operation, adjust the electronic bias voltage, IG1, to approximately 0.4V. Switch the light source to a monochrometer (Oriel model 77250 in our case), and focus the light on the spectrometer aperture. When 1 µm wavelength light is selected, the visible 0.5 µm wavelength is also present, and may be used to roughly place the beam at the right position. (The second order of the 0.5 µm beam is at the same position as the first order of the 1 µm beam.) Place the second order of the 0.5 µm beam at the short wavelength edge of the detector. The slit aperture image is easier to see than the pinhole aperture for this purpose. View the image by setting the software in the *difference wait* mode and setting the integration time from 0.1 sec. to 0.25 sec., depending on the wavelength (assuming the Oriel monochrometer as the source). First take a frame with the signal beam, then block the signal and take a background frame. The software will prompt the user for the right frame to take. (Note, because the signal-to-noise ratio is very low at room temperature operation, the signal will not be visible without background subtraction.) Adjust angle ψ of the grating until 1µm is just visible at the short wavelength edge of the detector. Set the monochrometer to 2.5 µm and repeat the software procedure to make sure that the long wavelength is present at the other edge of the detector. Since the monochrometer gives out multiple wavelengths at a given central wavelength (e.g. at 1 µm, both 0.5 µm and 2 µm light are also present), a variety of highpass, lowpass, and bandpass filters would be useful when trying to determine the wavelength incident on the detector.

g. The focus is the hardest alignment to adjust. Because the detected signal at room temperature is very low, the signal is buried in the noise on an oscilloscope trace. Also, the faint signal has a low FWHM (full width half maximum) since the maximum is very small, so the displayed signal line is much narrower than a cold temperature test would show. Therefore, we set the position of the detector at approximately the correct position at room temperature, and fine adjust the focus by successively adjusting the detector plane to achieve the best performance when the detector is cold. To set the detector at approximately the right position, expand and focus a HeNe (Helium Neon) laser such that the final beam is fast (f/3.5 – f/7). Align

the focus of the beam on the spectrometer pinhole aperture. Adjust the position of the grating along the optical axis such that the beam comes to a focus at the mid-travel of the detector mount. Then, move the detector mount back and forth along its slotted guide while observing the image spot on the detector. Set the detector at a position where the eye judges to be the best focus. This should be close enough to the actual focus to allow one to fine adjust by successive trials. Further adjustments involve cooling the detector, observing the image quality, warming the system back to room temperature, adjusting the position of the detector to a better focus, and repeating the process. This is a long process since each warm–cool cycle takes a minimum of two days.

D. Detector and Electronic Subsystems

1. Detector Array

The detector used in the spectrometer is a Rockwell TCM1000C 128x128 switched FET CMOS Mercury-Cadmium-Telluride Detector Array Multiplexer (HgCdTe). The detailed description of this detector is enclosed in the Rockwell manufacture's data sheets included with the Prototype Instrument Package.

a. Care and Handling of the Detector Array

The spectrometer utilizes a very expensive and fragile detector array that dictates a rigorous ESD (Electro-Static Discharge), and mechanical protection program. Any time the detector is handled or adjusted these safety precautions **MUST** be taken. To prevent electrostatic discharge when the chip and/or its container and the spectrometer are moved from one location to another location, (one potential to another potential) the potential change should occur across a very large resistance (≥ 1 Mohm) so that potentially damaging voltages are transferred into very small currents. The Rockwell detector should be prevented from ‘floating’, and should always be grounded to the DEWAR or other ground reference.

(1) **If at all possible,** leave the Interface Electronics Box attached to the spectrometer with the two interconnecting cables at all times.

(2) The main cable, power cable and filter wheel cable should only be connected to the Interface Electronics Box **AFTER** the two interconnecting cables are connected.

(3) All power supplies **MUST** be powered off when connecting to the Interface Electronics Box.

(4) **At all times,** when the two connections between the spectrometer and the interface electronics box are disconnected the two black round static foam pads **MUST** be installed into the two connectors (J20 and J21) located on the side of the spectrometer.

b. Installation of the Detector into the Spectrometer

The spectrometer **MUST** be prepared to receive the Rockwell detector before the detector is installed into the spectrometer. The electrical contact pins in the dewar of the spectrometer **MUST** be brought to the same ground potential as the detector

ground. Perform the following steps to bring the dewar to the spectrometer ground potential:

(1) Place conductive foam in contact with all the pins in connectors J20 and J21, located on the side of the spectrometer.

(2) Wrap the two connectors with aluminum foil, or put specially terminated connector plugs into connectors J20 and J21.

(3) Wrap the aluminum foil with silver bus wire or tie both of the multi-pin connectors together with silver bus wire, so that both connectors are tied to the same ground potential.

(4) Tie the silver bus wire to the same ground as the spectrometer.

Before you remove the Rockwell detector from the plastic box, the box should have conductive strips inside, the installer should tie himself to the spectrometer ground via a wrist strap and ground wire. Then open the plastic box and take a 1 Mohm resistor, or greater, and while holding one lead of the resistor touch the other lead to the conductive foam strips. This action will slowly bring the Rockwell detector to the same potential as the spectrometer ground. You can now remove the Rockwell detector from the plastic box and start the mechanical assembly.

The installation of the Rockwell detectors into the spectrometer is a task that should not be taken lightly, **MUST** not be rushed, and should not be done by anyone that has not received training on the handling and care of electrostatic sensitive electronics. The photosensitive area of the Rockwell detector and its associated logic is mounted onto a multi-layered ceramic package that has side edge contacts for its electrical connections. These edge contacts are indented to mate with appropriate spring contacts molded into the two blue edge connectors on the detector mounting block supplied with the spectrometer.

A thin (.005 inch thick) strip of Indium foil **MUST** be placed on the detector mount surface before the detector is installed. This Indium foil **MUST** also not interfere with the electrical contacts for the Rockwell detector. The soft Indium metal enhances thermal contact with the cooled copper mounting block.

On the ceramic detector package are two holes (see Configuration Drawing # SUBIS-40A-100); one elliptical hole on the center-line and one circular hole offset from the center-line. The two mounting holes must be aligned with the corresponding pins on the copper detector mounting block to ensure proper contact alignment to the detector and edge mounting connector.

Once the Rockwell detector is in place, the cover plate (with the order sorting filter in place) is mounted on top of the detector to form the final layer of the detector subassembly. The entire subassembly is now carefully bolted together by the two cap-screws near the ends of the cover plate. Before tightening be sure the bell-view washers are under the screw-heads and carefully inspect under magnification that all contacts on the detector are properly mated and that the detector is properly seated.

c. Installation of the spectrometer to a telescope

The spectrometer should be carried from its storage location to the telescope by one person. That person should be connected to the telescope via a 1Mohm bleed resistor, and after five seconds attached to the telescope with a wire without the bleed resistor. This assures that the person handling the spectrometer and the spectrometer is at the same electrical potential as the telescope. The spectrometer can now be bolted to the telescope. After the spectrometer is mounted, the Detector Interface Electronics Box can be mounted to the spectrometer in the same manner as mounting the spectrometer to the telescope. Finally, with the power off, the cables between the spectrometer and the Detector Interface Electronics Box can be connected, then the power supply cable can be connected, and lastly the main instrument cable from the HP RS-20 computer system can be attached.

2. Electronics Subsystems

The instrument electronics consists of a Hewlett-Packard (HP) RS-20 Vectra Computer, the Metrabyte PDMA-32 Interface Board, the power supply assembly, and a Rockwell TCM1000C 128x128 Mercury-Cadmium-Telluride Detector Array (HgCdTe), and the necessary electronics to provide clocking, reference voltages, analog to digital conversion, communications between the spectrometer and the HP RS-20 Vectra, and the Metrabyte High Speed DMA board. Detailed descriptions of the of the electronics follow in Sections a. through f.

a. Control and Interface Circuit Board

The Control and Interface Circuit Board is a full-length "AT" style circuit board that plugs into the HP Vectra's backplane. It contains the necessary circuitry that generates all of the timing signals for operation of the detector, data buffering for a full frame of data, and line drivers and receivers for the main cable. This board only obtains +5 vdc power from the HP Vectra's bus. Communication is through a Metrabyte Direct Memory Access (DMA) circuit board in an adjacent slot. Data is transferred up and down the main cable in serial format. Parallel to serial conversion is done by Advance Micro Devices (AMD) TAXIchip devices. TAXI stands for Transparent Asynchronous Transmitter/Receiver Interface. **NOTE:** *On the Control and Interface Circuit Board schematic , see* **Appendix I**,*the Transmit TAXI pins 1, 3, 4, 5, 7, 9, 11, and 23 and the Receive TAXI pins 1, 2, 3, 4, 5, 6, 7, 8, and 24 have pin numbers next to them in parentheses. The pin numbers in parentheses are the actual pins on the TAXI device ,whereas the other pin numbers are the pin numbers of the connector on the daughter board.*

A 10 MHz oscillator, U1, divided by one section of a 74LS393, U7, provides the time-base for this circuit. This is further divided down by the other half of U7 to provide the 6.4 microsecond master clock, **MCLCK**. A 3.2 microsecond MCLCK may be obtained by connecting pin 13 of U7 to pin 4 of U7 instead of pin 5 and likewise a 12.8 microsecond MCLCK by connecting pin 13 to pin 6 of U7. A 74F269 8 bit counter, U17, divides MCLCK by 133 to generate the **YSYN** pulse for the detector. This division of 133 is selected by a wire-wrapped input to a 74LS682 8-bit comparator, U25, whose output is deglitched with a section of a 74HC574 octal latch, U27, clocked at the MCLCK rate. The deglitched equal to 130, now actually 131 after the latch, is fed to the parallel enable input of U17 to preset the counter to 255 at count 132. The next clock, 133, increments the counter from 255 to 0 giving

the divide by 133. This may be adjusted, if desired, by changing the wire-wrapped code at the Q inputs of U25. Only the pins to be pulled low need to be connected as the 74LS682 has internal pull up resistors on the Q inputs. The YSYN signal is put into the proper time slot by delaying through two more sections of U27.

A similar counter, U16, and comparator, U24, are used to control the number of columns that are read out. Half of a 74LS74 flip-flop, U10, controls the parallel enable of counter U16. Pin 6 of U10 is normally low and forces the counter to be constantly preset to a count of 255. At the end of FRAME pin 6 goes high allowing U16 to increment until it reaches a count of 130. Comparator U24 detects 130 and is deglitched by a section of U27 and used to preset U10 which again causes U16 to be preset to 255. The other half of U10, one gate of U9, and one gate of U11 combine to produce 128 columns of 128 A/D start convert pulses, or 16,384 total pulses.

The **FRAME** pulse, or integration time, is determined by 74F269 counters U13, U14, and U15 that form a 24-bit count down timer. The time base to this counter is the YSYN pulse whose period is 851.2 microseconds. The initial count is loaded from three 74HC574 octal latches, U21, U22, and U23, that are loaded one at a time from the Metrabyte A data bus. A 74LS74 flip-flop, U4, controls operation of the FRAME counter. The first half of U4 catches the start integrate command while the second half synchronizes this request to the YSYN clock. The FRAME signal is tied to the parallel enable lines of the counters. When FRAME is not true the counters are continuously loaded with the contents of the octal latches. When FRAME goes true the counters count down to zero. The terminal count line, pin 14 of U13, is deglitched by a section of U27 and used to preset the first half of U4 which results in the end of FRAME one YSYN period later. Therefore the integration time is always n+1 YSYN periods. The contents of U21, the most significant byte of the integration time, are compared to a value of 1 by comparator, U26, to generate a clock shutdown signal for long integrations. A value of 1 corresponds to a period of about 55.78 seconds. U31 pins 8, 9, and 10, logically OR the greater than and equal to outputs of U26, together to generate the halt clocks condition. For long integrations the detector clocks and on chip preamps must be halted, but not before the FRAME pulse has been clocked completely across the array. Therefore U28, a 74LS393 counter, and half of U29, a 74LS74 flip-flop are used to delay this shutdown until 256 YSYN periods have elapsed.

Commands to the Control and Interface Circuit Board are sent through the Metrabyte Board from the control software. Instruction codes are placed on the A data bus and loaded into a 74LS174 hex latch, U19, with the **AUX 1** pulse from the Metrabyte. If there is data associated with the instruction it is then placed on the A data bus. The instruction is decoded by a 3 to 8 line 74LS138 decoder, U20, and executed by the **AUX 2** pulse enabling pin 6 of U20. Instruction codes 0, 1, and 2 are used to load the three FRAME time latches. Code 5 is used to load the filter wheel control register U33, a 74LS174 hex latch. Code 6 is the continuous run command and code 7 is the single frame start command. Continuous run or single frame operation is controlled by the state of the first half of U2, a 74LS74 flip-flop in conjunction with three sections of a 74LS00 NAND gate, U32. When continuous run operation is desired a normal code 7 start command is issued and followed immediately by a code 6 which resets U2, allowing a pulse which occurs at the end of the read operation to pass through pin 10 of U32 and restart the sequence. Continuous mode is terminated by issuing a single frame command.

Communication between the Detector Interface Electronics and the Control and Interface Circuit Board takes place over a cable of 9 shielded twisted pairs. Most of the logic level signals are sent in a serial data format that utilizes a high performance chip set from AMD known as the TAXIchip set. The TAXIchip set consists of an AM7968 Transmitter, which takes parallel data and transmits it serially at 32 MHz, and an AM7969 Receiver, which converts the serial data stream back to parallel form. This system sends 8 bit words up one of the twisted pairs in the main cable at four times the MCLCK rate or one every 1.6 microseconds. Two of the data bits sent are related to controlling data from the A/D converter that is sent down the return link. Bit D0 is the byte select line that goes to the A/D converter and selects whether the high or low order 7 bits of each 14 bit conversion are connected to the return TAXI transmitter. Bit D1 is known as the active bytes signal and comes from pin 6 of a 74LS74 flip-flop, U30, that is clocked by the trailing edge of the A/D start convert signal. The conversion starts on the negative transition and is complete by the time of the rising edge. In the Detector Interface Electronics this signal is ANDED with the received data strobe and used to strobe the return transmitter twice, once for the high byte and once for the low byte. The inverted byte select signal is returned as the eighth bit of each byte. These bytes are then received after coming down the reverse serial link. They are directed with steering logic to two IDT7M206S 16K x 9 bit **FIFO** modules, U5 and U6. Other signals sent up are the YSYN clock as D2, the FRAME signal as D3, the two preamp control signals as D4 and D5 and a multiplexer control signal as D6. At present D7 is unused. The TAXI may also be configured for up to 10 bits if needed. Please refer to the AMD data sheets included with the Prototype Instrument Package. The MCLCK and A/D start convert signal are not sent through the TAXI since they need to maintain exact phase coherence to avoid adding unwanted noise to the sampling of the video signal. A 75174 differential line driver, U18, sends them on two other twisted pairs.

After the array is read out and the FIFO's are filled the data is transferred through the Metrabyte DMA interface to the Vectra computer's memory. The first DMA transfer request is initiated by U10 pin 9 going high and clocking flip-flop U8. Data from the first half of U8 is presented to the second half of U8 which is clocked by the 10 MHz clock. After it is clocked through it is used to preset the first half of U8. This generates a 100 nanosecond pulse at pin 9 of U8 that is used as the XFER REQ IN to the Metrabyte which responds with a low going XFER ACK OUT. The rising edge of this signal indicates that the transfer is complete and is used to initiate the next request. The XFER ACK OUT signal is quite noisy so it is filtered by passing it through half of a 74LS74, U34. A short pulse is generated from the rising edge of this signal by flip-flop U2 and used to reset the first half of U8, thus generating a new XFER REQ IN signal. U3, a 74LS74 flip flop, is used to generate the **READ** signal for the FIFO's. Since this causes the tri-state outputs of the FIFO's to be enabled onto the Metrabyte bus there must be some arbitration. Either the **A DIRECTION OUT** signal from the Metrabyte or U4 pin 5 will inhibit the FIFO's from being enabled. The A DIRECTION OUT signal is also quite noisy and is therefore filtered with the other half of U34.

b. Detector Interface Electronics

The Detector Interface Electronics Box is mounted directly to the side of the spectrometer. It contains circuitry that must be close to the detector. The signal processing, analog to digital converter, and bias voltage generators comprise one circuit board. The second circuit board has the pulse drivers for the detector and the

line drivers and receivers for the main umbilical cable. There are also circuits for parallel to serial and serial to parallel data conversion. A terminal strip allows for connection to other conductors in the main cable. Two Omega Engineering digital transmitters connect to platinum RTD temperature sensors located inside the spectrometer.

There are two video outputs from the detector array that are brought to an HI-387 SPDT CMOS analog switch, U3. These two signals correspond to the two halves of the array. Columns 1-64 are read out first and then the control of the switch is changed and columns 65-128 are read out. The output of the switch is applied to the negative input of the INA110 instrumentation amplifier, U2, and an adjustable potential is applied to the positive input of U2. The adjustable potential is derived from the voltage divider of R36, R35, and R37 and filtered by C37. This inverts the video signal so that increasing signal is positive and zero signal may be placed at a small positive potential. The gain of the INA110 instrumentation amplifier, U2, is adjustable from 0.8 to 3.5 by adjusting R34. The range of the gain can be changed by strapping the appropriate pins together on the INA110 amplifier, U2 (see the manufacture's data sheet included with the Prototype Instrument Package.). The output of the instrumentation amplifier is applied directly to the input of the ZAD2764 14 bit high speed sampling A/D converter. The resolution of the A/D converter as applied to the Rockwell detector is discussed in Section II.F.4, Test Results subsection Intensity Resolution. Power for the on chip preamplifiers is supplied by a TSC1427 MOSFET driver, U1, driven by TTL logic levels. Separate control for each preamp is provided all the way back to the control logic although they are currently driven in parallel as per Rockwell's latest recommendation. There are a number of separate voltage regulators on board for the various loads. Input power is +/-18 vdc that is regulated to +/-15 vdc by VR5, a LM317H, and VR4, a LM337H, respectively for the A/D converter. VR2, a LM317H, provides +5 vdc through a jumper for the A/D converter. This optional jumper can be installed for a potentially quieter supply if needed. The +5 vdc is now provided through J18. VR1, a LM317H, generates +10 vdc for the bias networks and for the detector VDD supply. VR3, a LM317H, derives its reference from VR1 and also generates +10 vdc for U1, the on chip preamplifier supplies. The bias networks are self explanatory and each is supplied with a test point.

The other circuit board, the Taxi Interface Electronics, interfaces with the main instrument cable. It contains an AM7969 TAXI receiver, U5, and an AM7968 TAXI transmitter, U4. Data from the A/D converter is presented as a high order byte followed by the low order byte to the TAXI transmitter for transmission down the main instrument cable. The control signals for byte select and active bytes as previously described come from U5. The MCLCK and A/D start convert trigger come from U3, a DS8820 differential line receiver. Two TSC1427 MOSFET drivers are used to buffer and level shift the MCLCK, YSYN, FRAME, and control signal for the analog switch on the other board. Power for these drivers is +10 vdc derived from a LM317H voltage regulator, VR1, that is supplied by the +18 vdc supply. The Omega digital temperature transmitters and the controls to the filter wheel are connected via terminal strip T1. T1 is located on one side of the circuit board and is used to extend the remaining shielded pairs in the main instrument cable.

c. Power Supplies

The power supplies for the spectrometer instrument are housed in a separate box. Two separate linear power supplies, one for the +5 vdc and one for the +/- 18 vdc, are utilized to ensure low noise operation. The Texas Instrument Camera requires a +/-15 vdc power supply, not furnished by SETS, Inc., for its operation. The manufacturer's data sheets for the camera are included with the Prototype Instrument Package. The filter wheel assembly has its own power supply and manual control circuitry. The HP Vectra can communicate with the filter wheel electronics for automatic selection of the filter for the T.I. camera.

d. MetraByte Direct Memory Access Board.

The MetraByte PDMA-32 is an IBM PC/AT 16-bit digital input/output interface board. The board has 8-or 16-bit direct memory access capability (DMA). By using the full 16 bit data bus the data transfer rate can be up to 200,000 16 bit words per second in either input or output modes. The PDMA-32 provides two 8-bit I/O ports. Each port can be set as an input or output while the board is under software control, and each of the ports can be addressed as normal I/O locations. However the spectrometer operates the PDMA-32 in the high speed DMA mode, so both ports are set to operate in the same direction.

The actual DMA transfers are initiated by an external signal (XFER request). On receipt of a positive edge on the XFER REQ input the XFER ACK output goes low. Completion of the transfer is signified by the XFER ACK output returning to the high state. This allows for simple handshaking at high DMA speeds.

The PDMA-32 also has three auxiliary output bits, called AUX 1, AUX 2, and AUX 3. These three outputs are used to control the spectrometer, as explained in the Section II.D.2.a Control and Interface Circuit Board.

The PDMA-32 also has one interrupt channel provided. This software controlled interrupt allows the interrupt to be selected as active or not active with the interrupt level between interrupt two through seven. The interrupt is positive or negative selectable from software control. An active interrupt from the spectrometer causes a terminal interrupt to be generated by the PDMA-32's 8327 DMA controller.

e. Hewlett Packard RS-20 Vectra Computer System.

The Hewlett-Packard Vectra RS-20 Personal Computer system is a high performance, industry-standard, floor-mount personal computer based on the Intel 80386 microprocessor. The system includes the Intel 80386 20 Mhz microprocessor, the Intel 80387 20 Mhz math co-processor, 2 MB random access memory, a 9-pin serial port, a 25-pin parallel port, a 330-watt power supply, a 512K byte VGA Color graphics card with a VGA Color monitor, a 1.2 MB 5 1/4" floppy disk drive, a two-button mouse, and a 103 MB hard disk drive with controller.

The RS-20 Vectra is programmed to control and collect data from the spectrometer. When the RS-20 is being used to control and collect data from the spectrometer it can not be used to perform other software or hardware tasks. The control software is written in Microsoft C version 5.1 and Microsoft Assembler version 5.1. MS-DOS version 3.20 is used as the operating system for the HP RS-20 Vectra.

f. Cables.

The spectrometer instrument is connected via a number of interconnecting cables and wiring harnesses. The illustration labeled "OVERALL CABLING AND INTERCONNECTIONS" is the main reference for connecting up the instrument, see Appendix I. The designator in parentheses is the connector label and the label before or after the parenthesis is the connector part-number or type of cable, (i.e. PT02A20-27P or FLAT CABLE). Appendix I shows the wiring of each cable or wiring harness, just look up the Cable Name to find its wiring.

The following cables connect the main assemblies. The Power Supply Assembly connects to the Interface Electronics Box via the Main Power Cable. The HP Vectra computer system is connected to the Interface Electronics Box via the Main Instrument Cable. The spectrometer instrument is connected to the Interface Electronics Box via the Spectrometer Main Cable and the Spectrometer Control Cable. The following table labels the cables used to connect the different assemblies:

CONNECTOR LABEL	CONNECTOR LABEL	CABLE NAME
(P17) PT06A14-19P	PT06A14-19S (P20)	Spectrometer Control Cable
(P16) PT06A16-26P	PT06A16-26S (P21)	Spectrometer Main Cable
(P18) PT06A18-11S	PT06A18-11P (P22)	Main Power Cable
(P8) PT06A20-27S	PT06A20-27P (P7)	Main Instrument Cable
(P23)	PT06A10-6P (P19)	Filter Wheel Control Cable

The Interface Electronics Box has three flat ribbon cables and three wiring harnesses as to connect the internal assemblies and to connect these assemblies to the outside units. The following table labels these cables and wiring harnesses used to connect the Interface Electronics Box and its internals to the other assemblies:

CONNECTOR LABEL	CONNECTOR LABEL	CABLE NAME
(P15) FLAT CABLE	PT02A16-26S (J16)	Detector Interface to Spectrometer Main Cable
(P12) FLAT CABLE	PT02A14-19S (J17)	TAXI to Spectrometer Control Cable
(P9) FLAT CABLE	PT02A20-27P (J8)	TAXI Interface to Main Instrument Cable
(P10) FLAT CABLE	FLAT CABLE (P13)	TAXI Interface to Detector Interface Cable
(T1) WIRING	WIRING (J19)	TAXI Interface Wiring

(J18) WIRING	WIRING (P11) (P14)	Detector Interface Power Supply Harness

The Hewlett-Packard RS-20 Vectra computer system has a Metrabyte PDMA-32 circuit board and the Control and Interface Electronics circuit board installed in the Vectra's backplane. These two circuit boards interface with the Vectra, the Vectra's Communications Port (COM1), and the Interface Electronics Box. The following Table labels the cables used to connect the Vectra to the the spectrometer:

CONNECTOR LABEL	CONNECTOR LABEL	CABLE NAME
(P3) FLAT CABLE	PT02A20-27P (J7)	Control Interface to Main Instrument Cable
(P5) FLAT CABLE	FLAT CABLE (J6)	Serial Interface Cable
(P3) FLAT CABLE	FLAT CABLE (P5)	Serial Connector to Control Interface Wiring
(P1) FLAT CABLE	FLAT CABLE (P6)	COM1 to Serial Connector Cable
(P2) FLAT CABLE	FLAT CABLE (P4)	Control Interface to Metrabyte Cable

The spectrometer has just one internal wiring harness. This wiring harness connects the two Omega RTD's to the Interface Electronics Box and connects the Rockwell detector to the Interface Electronics Box. This wiring harness is labeled as "DEWAR WIRING". See this drawing in Appendix I for these connections.

E. Software

The software for the spectrometer was developed on a 20 MHz 80386 computer running MS-DOS. The main functions of the software are:

- The control of the instrument
- Acquisition and storage of both data and status information
- Display of the data and status information
- Primary data analysis
- Communications with other computer systems

1. Instrument Control

Control of the spectrometer is handled through the high-speed I/O board (MetraByte PDMA 32) which is directly coupled to the Spectrometer Control Board via a flat ribbon cable. This gives software control of the integration time, start of data collection, control of the filter wheel, and additional commands for later expansion. The software control of the instrument is handled through a set of eight commands which can be sent, with any associated data, to the Spectrometer Control Board. These commands are:

Command	Description
0	Load Low Byte of the Integration Count
1	Load Middle Byte of the Integration Count
2	Load High Byte of the Integration Count
3	Unused
4	Unused
5	Load Filter Wheel Position
6	Unused
7	Start Integration

The execution of any command involves a set of steps which send that command and its associated value to the control board and then execute that command. These steps are:

a. Set the PDMA Port A for output.

b. Load the command into the Port A register.

c. Load the command into the command register of the control board.
   (1) Set the AUX 1 flag.
   (2) Clear the AUX 1 flag.

d. If the command has a value associated with it, load that value into Port A register.

e. Execute that command.
   (1) Set the AUX 2 flag.
   (2) Clear the AUX 2 flag.

f. Set Port A back to input mode.

Note that sending any commands during data collection would lead to undetermined results and could adversely affect the data collection. Under normal operations, the software doesn't allow this to occur. However, if the operator inadvertently starts a long integration, it can be stopped by resetting the computer system and the Interface Electronics Power Supply, thereby throwing away the current data collection.

2. Data Collection

The software provides the operator with several modes of data collection depending upon the experiment and collection conditions. These modes are:

a. Average

The Average mode of data collection allows the operator to average sequential frames of data and to store the results of that average. This mode is useful when the background limits the integration time.

b. Difference

The Difference mode of data collection allows the operator to take the average of the difference between successive frames. This mode is useful for continuously switching between the background and the desired source.

c. Sum

The Sum mode of data collection allows the operator to take the sum of sequential frames of data and store the accumulated value of that sum. This mode is identical to the Average mode except it does not divide the sum by the number of frames acquired, therefore increasing the speed of the data collection.

d. Difference Sum

The Difference Sum mode of data collection allows the operator to take the sum of the differences between successive frames and to store the accumulated difference. This mode is identical to the Difference mode except it does not divide the sum by the number of pairs of frames acquired, therefore increasing the speed of the data collection.

e. Difference with Wait

The Difference with Wait mode of data collection allows the operator to select when the sample and reference data is collected by using the enter key to start data collection. This mode is used in the laboratory to remove the background and is especially useful at room temperature.

All of these modes of data collection can be used either for acquiring single frames of data or for mapping of an object. The data is read into the computer system using the high-speed MetraByte board via DMA access. This nominal data transfer rates at up to 200 Kbytes/sec. Therefore during normal operations a frame of data can be collected at rates up to 2 frames/second, with the additional time due to the processing time in the computer system.

3. Data Display

a. Color Palettes: An acquired or previously stored data file can be displayed on the monitor of the computer. The monitor is a standard VGA color monitor with 480 x 640 pixel resolution, using an extended VGA adaptor with 512K of memory, to enable the display of 256 colors at a resolution of 480 x 640 pixels. The software allows the operator to select the color palette used to display the active data set and the linear scaling used for mapping the data values to color values. Currently the system supports 5 color palettes:

(1) Rainbow: The Rainbow palette displays the data values using the entire spectrum of colors.

(2) Red: The Red palette displays the data values using various intensities of red, with the low data values being black and the high data values being bright red.

(3) Green: The Green palette displays the data values using various intensities of green, with the low data values being black and the high data values being bright green.

(4) Blue: The Blue palette displays the data values using various intensities of blue, with the low data values being black and the high data values being bright blue.

(5) BW: The BW palette displays the data values using a gray scale, with the low data values being black and the high data values being bright white.

b. New Palettes: New palettes can be added, however this process would require creating both a palette file and adding a new entry into the palette selection menu. The data can be stretched in several ways:

(1) Fixed Scale: The Fixed Scale of data stretching allows the operator to enter the minimum data value and the maximum data value to map the color table too. Data values below the minimum get mapped to a minimum color value and data values above the maximum are mapped to maximum color value.

(2) Dynamic Scale: The Dynamic Scale mode determines the minimum and maximum data value and maps the color map linearly over that entire range of data values.

c. Viewing in other formats: Beside being able to display an image of the data, the operator can also view the data in other fashions to aid in analysis. These methods are:

(1) Plot: The Plot function produces a X-Y plot of any of the three axes of the data current data set and allows the operator to specify a range in the other two axes to be averaged for generating the intensity data for that plot. This function essentially provides line profile of the data.

(2) Histogram: The Histogram function produces a graph of the number of pixels having an intensity value within a given range versus intensity. The resulting graph is useful when setting the scale for displaying the data.

(3) Statistics: The Statistics function calculates the basic statistics on the present data set of a specified portion of that data set.

(4) View: The View function allows the operator to look at the actual data values for each of the pixels in the present data set and to modify those values if necessary.

4. Data Analysis

The data analysis software allows the operator to perform mathematical operations on the data for simple calibration data manipulation. The data analysis routines incorporated into the software package are:

a. Add

The Add function is used to add either a constant or another data set to the current data set. The resulting data set can then be viewed and stored on the computer.

b. Subtract

The Subtract function is used to subtract either a constant or another data set from the current data set. The resulting data set can then be viewed and stored on the computer.

c. Multiply

The Multiply function is used to multiply the current data set by either a constant or another data set. The resulting data set can then be viewed and stored on the computer.

d. Divide

The Divide function is used to divide the current data set by either a constant or another data set. The resulting data set can then be viewed and stored on the computer.

5. Communications

The computer system includes a Ethernet card and TCP/IP software for transferring the data sets to other computer systems for further manipulation and storage.

F. Test Results

This section discusses the tests and the results conducted on both the individual subcomponents and the instrument as a system.

1. Spectral Range

The spectral range of the system is approximately 0.88 - 2.62 µm. The test source is an Oriel monochrometer spectrally calibrated with a Mercury low pressure pencil lamp. Argon and Krypton low pressure lamps were also employed as wavelength standards in the NIR, e.g., Ar (1.69 & 1.37 microns) and K(2.19 & 1.8 microns).

2. Vacuum and Cold Tests

Two resistance temperature devices, RTDs, are installed in the spectrometer. RTD 1 is mounted in the detector mount, and RTD 2 is mounted on the optical bench at the rear of the detector assembly. Two Omega digital transmitters, mounted in the main electronics box, interface the temperature sensors with the Vectra's RS-232 input. The temperature readout was achieved by using the SCAN program in the HP Vectra's C:\OMEGA directory. (The program SCAN was used because at the time of testing the spectrometer software program did not have the existing temperature readout function.) At room temperature, both RTD 1 and RTD 2 read 29.2 °C, and at 77°K (achieved by immersing the RTDs in liquid nitrogen), RTD 1 reads -194°C, while RTD 2 reads -193°C.

The hold time of the spectrometer box was measured for the up-looking and side-looking nitrogen tanks. Only one liquid nitrogen tank was filled for each test. The RTD used to measure the hold time is the one mounted in the detector mount, RTD 1. The hold time is measured by filling the desired tank with liquid nitrogen, wait until the rate of evaporation of liquid settles (the "smoking" subsides, in about an hour), top off the tank again and start the time counter. The RTD temperature is then sampled every five minutes and the hold time is from the start time to the time when the RTD temperature raises a degree. In the up-looking orientation, the hold time was about nine hours without the getter, and eleven and a half hours with the getter. In the side-looking orientation, the hold time was six hours without the getter, and nine hours with the getter. Although the hold time for

the side-looking mode is shorter, the temperature achieved in this mode is 1°C lower than the up-looking mode: -191°C versus -190°C, as measured by the RTD. Therefore, if we define the hold time as the time it takes to get below -190°C for both tanks, then the hold time for the side-looking tank increases to eleven hours. The fact that the getter made a big difference in the hold time suggests that residual gas is the main factor determining the hold time, and a good vacuum should be achieved by pumping for forty-eight hours before cool down. When two to four layers of superinsulation were wrapped around the cold-shield and the liquid-nitrogen tanks, the hold time did not improve. Since there is not enough room for more layers of superinsulation, we do not suggest using superinsulation to improve the hold time. Instead, ensure a good vacuum and fill half of the unused tank with liquid nitrogen, as well as a full tank of the desired configuration.

The engineering grade detector (new, replacement for the delaminated engineering detector) has been cold cycled at SETS 19 times. This includes the cold cycle at the final review. No signs of degradation due to cold cycling of this detector have been observed.

3. Background and Dark Current Tests

Background and dark current were measured at the normal operating temperature of 77°K. The background current measurements were made (except for 4) with the aperture wheel set at a blocked half-position and under the following conditions: (1) detector blocked off with a cold stop and presumably "blind" to all external sources to establish the minimum dark current value, (2) exposed to the spectrometer environment (with stray-light baffle in place) with a test aperture of the same opening as the detector active area and without the order sorting filter, (3) same as (2) but with the current installed detector cover plate holding the custom order sorting filter, (4) same as (3) but with the aperture wheel set at the slit aperture and (5) same as (3) but without the baffle screen. Measurement (4) gives the background and dark current to be expected in the imaging mode. The smaller opening in the test holder of (2) (not supplied with the spectrometer) presents a smaller field of view to the detector and thus the lower derived current value observed. A series of integration times was conducted to provide the data for the quoted dark and background current values. The background and dark current measurements were calculated for two regions of the detector, regions A and B, to compare shorter wavelengths with longer wavelengths. Region A consists of rows (the rows and columns are in terms of the software nomenclature) 20–60 and columns 10–60. Columns 10–60 corresponds to the wavelength region of 2.5–1.8 μm. Region B consists of rows 75–115 and columns 75–125. Columns 75–115 corresponds to the wavelength region of 1.6–0.9 μm. Table IV shows the measurement results.

Table IV. Background and Dark Current Measurements.

Measurement	Ibk+dc Section A (e-/sec)	Ibk+dc Section B (e-/sec)
(1) Detector totally blocked with cold stop	10	10
(2) Detector blocked with small test aperture	750	185
(3) Detector as in current setup	1040	400
(4) Same as 3 but with aperture wheel at the slit position	5340	670
(5) Same as 3 but without the baffle screen	19840	20140

The calculations in Table IV assume that it takes 20 million electrons (fullwell of the Rockwell detector) to bring the minimum intensity value of zero counts to the maximum intensity value of 4261 counts at saturation. Note, these measurements were taken with the gain of the amplifier equal to one.

4. Intensity Resolution

The intensity resolution is determined by the 14-bit A/D converter and can be easily improved by replacing the A/D converter with a higher resolution A/D converter. The range of acceptable input voltages into the A/D converter is from 0 to 10 volts. To use the full dynamic range of the A/D converter, a variable gain is provided for the amplifier. The detector output voltage into the amplifier varies from approximately 0 to 3 volts. The amplifier gain varies from approximately a factor of 3.5 to less than one. At the maximum gain, the intensity values (as displayed by the software) range from 530 to 11766, and at the minimum gain, the intensity values range from 0 to 2024. Thus, the minimum dynamic range to the maximum dynamic range varies by a factor of approximately 5.8. (See the electronics section on more details about the gain adjustment.) For a fullwell of 20 million electrons, we then have 1700 electrons/intensity count at the maximum gain, and 9881 electrons/intensity count at the minimum gain. Since the readout noise of the system is expected to be about 500 electrons, we will not be able to resolve the readout noise.

C. Operation of the Spectrometer

Before operating the spectrometer, read Section II.D.1 on care and handling of the detector and Section II.B.2 on vacuum handling procedure. To operate the spectrometer, attach the filter wheel-CCD camera assembly to the spectrometer, before the Interface Electronics Box is mounted. Then, attach the Interface Electronics Box to the lid of the spectrometer box with the four mounting screws. This brings the interface electronics to the same potential as the spectrometer (and thus the detector). Therefore, if one operates the spectrometer with the Interface Electronics Box detached from the spectrometer box, it is important to bring a lead from the ground wire of the interface electronics to a point on the spectrometer dewar housing (for example, one of the two ferro-motor mounts). The next step is to make sure that the power supply is off and then remove the two circular static foam pads from the spectrometer connectors and connect the two interconnecting cables from the Interface Electronics Box to the spectrometer. Then, connect the power cable, main cable and filter wheel cable to the Interface Electronics Box. Hook up the CCD camera to the video screen and a ±15V power supply with the cables provided. Turn on the video screen and then the CCD camera power supply. The CCD camera is very useful for rough alignment of the object focus on the spectrometer aperture. Connect the main cable to the HP Vectra computer and turn on the computer. After checking all connections, turn the electronics power on.

For room temperature operation, set the bias voltages to the following values (these are for the Rockwell engineering detector only, since the optimal bias level for each detector is a little different): LG1 = 2.0 V, LG2 = 2.2 V, IG1 = 0.4 V, IG2 = 1.5 V, VC = 6.8 V and VINV = 2.6 V. Because the dark current is so large at room temperature, the best way to detect a signal is by using the *diff. wait* mode of the software with an integration time of about 0.1 second. For liquid nitrogen temperature operation, change IG1 to 1.11 V, and select an integration time from 1.16 msec to 1.7 hours.

To use the spectrometer control software, type **viris** at the DOS command prompt. The pull-down menu driven software is relatively straightforward. Set up the desired operation mode

by following the instructions in the software section or use the software HELP function. To start data collection, type *shift-F3* .

If all the connections are correct and all the components are operating correctly there will be an image on the computer display. One can then continually collect data by typing *shift-F3* or modify the setup to perform other types of collection and display of data. If any problems arise read this entire report for proper operation of the spectrometer. Remember, this is an expensive scientific instrument and should be treated as such.

III. CONCLUSIONS and RECOMMENDATIONS

The design and operating characteristics of a groundbased imaging spectrometer have been described. The instrument uses a novel approach for an imaging spectrometer. The resultant instrument is compact and optically efficient.

Although the instrument has been sufficiently tested to determine that the design is successful, the instrument is a prototype. Before the instrument can become a top-rate groundbased imaging spectrometer, several enhancement tasks are recommended below:

A. The grating should be replaced by one specifically made to prevent the delamination problem.

B. The engineering grade detector installed in the spectrometer should be replaced by the science grade detector.

C. The horizontal line 64 is currently nonoperable and should be fixed.

D. The new elements (grating and science grade detector) should be realigned and fully calibrated.

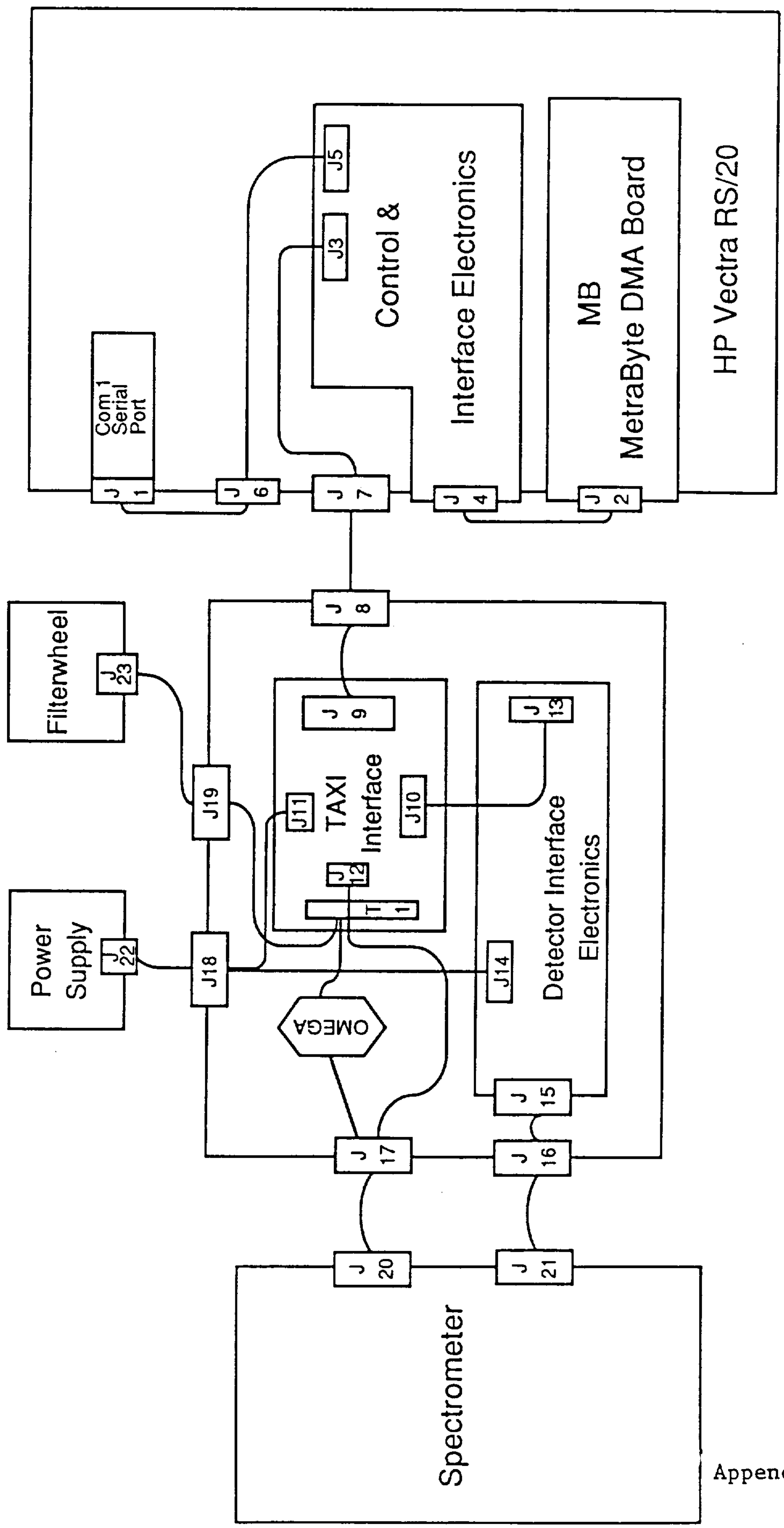
E. The baffle and detector cover plate should be fine-tuned to reduce thermal background current.

F. The temperature sensor diode on the detector chip should be calibrated.

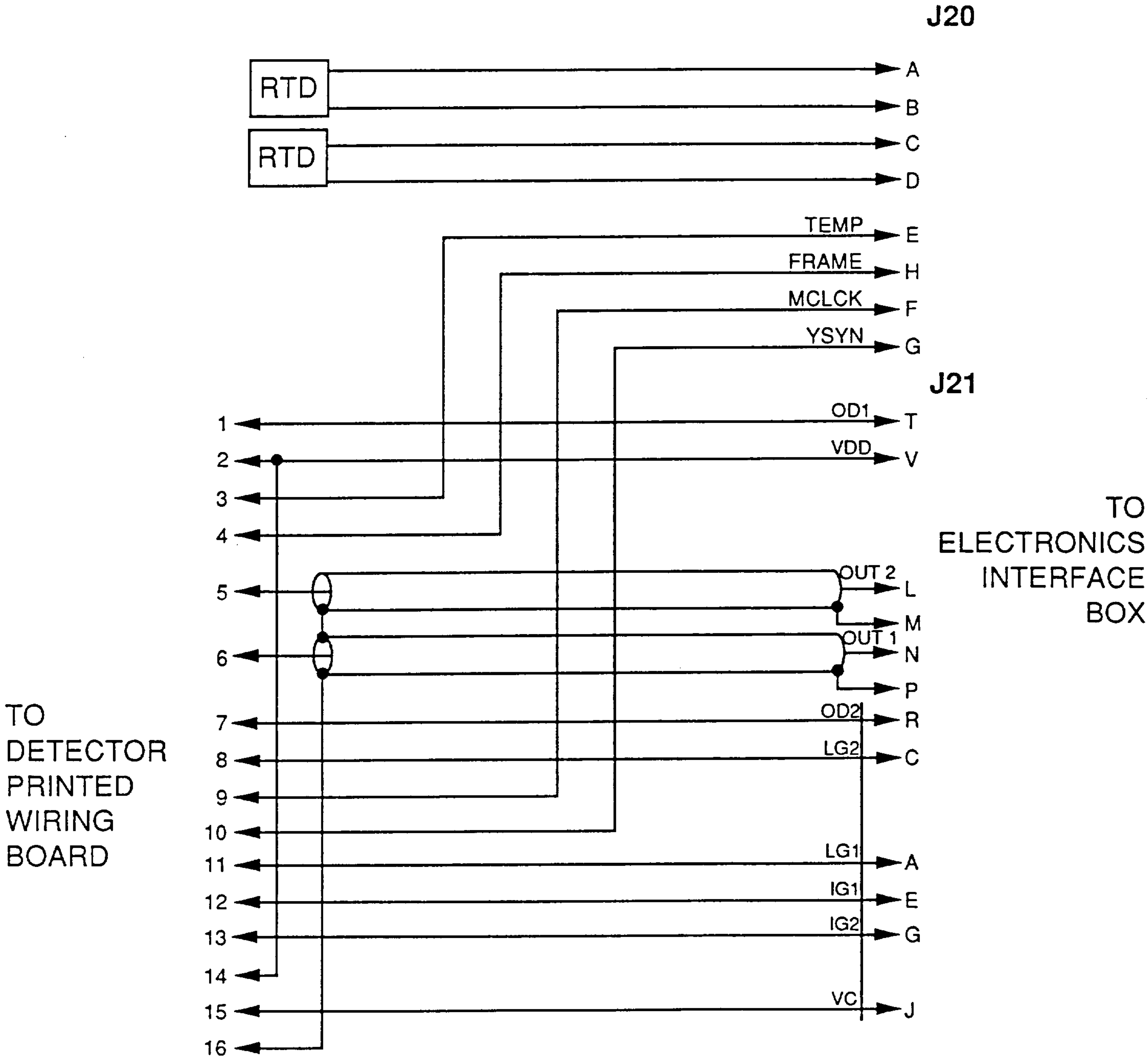
This instrument has significant potential due to its unique design. The instrument is especially suitable for commercial applications. SETS, Inc. has taken steps to commercialize the instrument, and we have high hopes for the results of this imaging spectrometer SBIR program.

Page	Electronics Drawings Listing
1	Overall Cabling and Interconnections
2	Dewar Wiring
3	Spectrometer Control Cable
4	Spectrometer Main Cable
5	TAXI to Spectrometer Control Cable
6	Detector Interface to Spectrometer Main Cable
7	TAXI Interface Wiring
8	TAXI Interface Board J9 to T1
9	TAXI Interface to Detector Interface Cable
10	Power Supply for Interface Electronics Box
11	Main Power Cable
12	Detector Interface Power Supply Harness
13	Texas Instruments Camera
14	Filter Wheel Control Cable
15	TAXI Interface to Main Instrument Cable
16	Main Instrument Cable
17	New Vectra Board Layout
18	Control Interface to Main Instrument Cable
19	Serial Connector to Control Interface
20	Control Interface to MetraByte Cable
21	COM1 to Serial Connector Cable
22	Serial Interface
23	Instructions for IBM AT Plugbord (4617 series)
24	Taxi Interface Electronics Layout
25	Detector Interface Electronics Layout
26	Schematic: Taxi Interface Electronics
27	Schematic: Detector Interface Electronics
28	Schematic: Control and Interface Circuit Board (2 sheets)

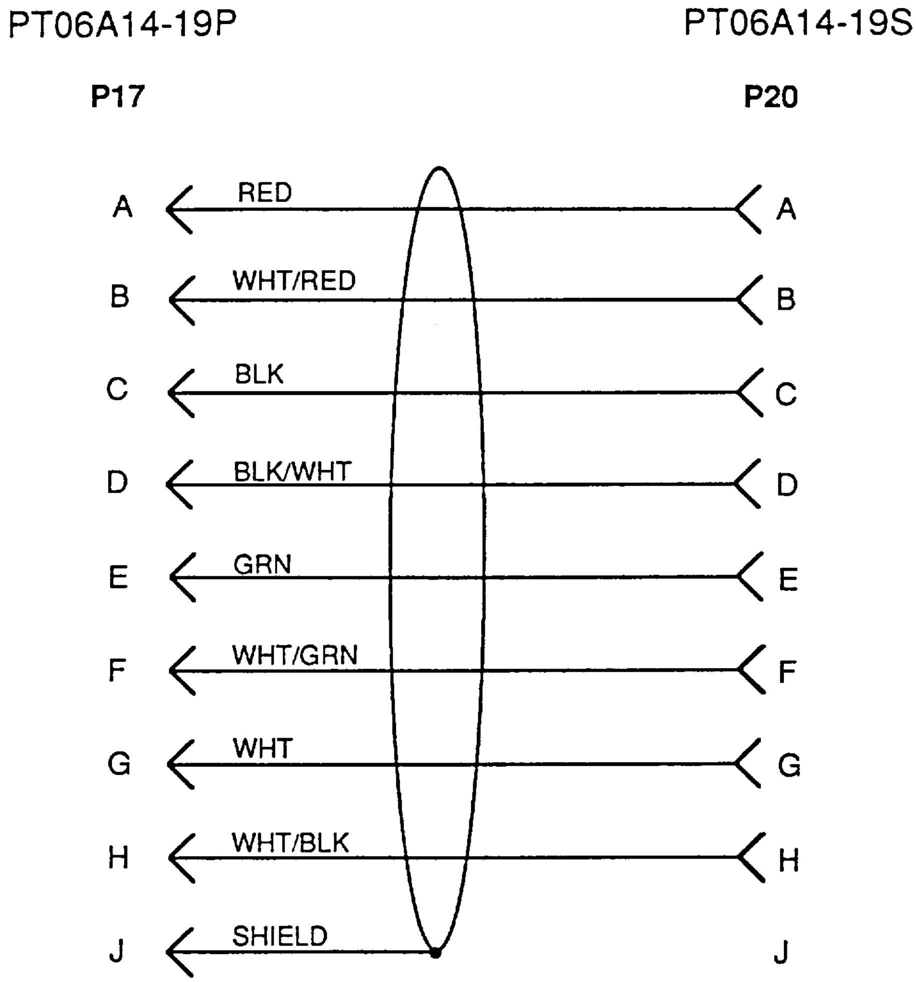
OVERALL CABLING and INTERCONNECTIONS



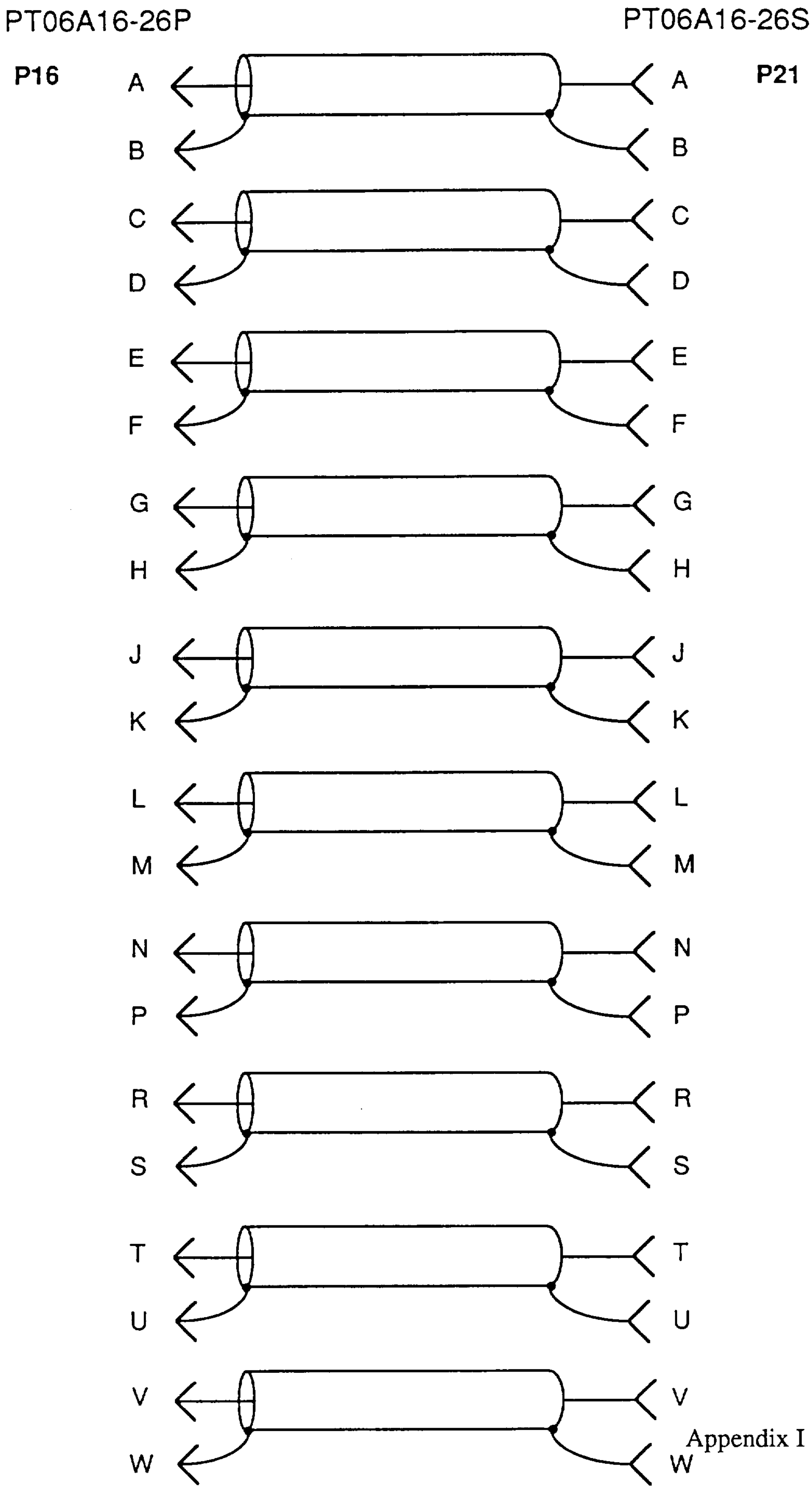
DEWAR WIRING



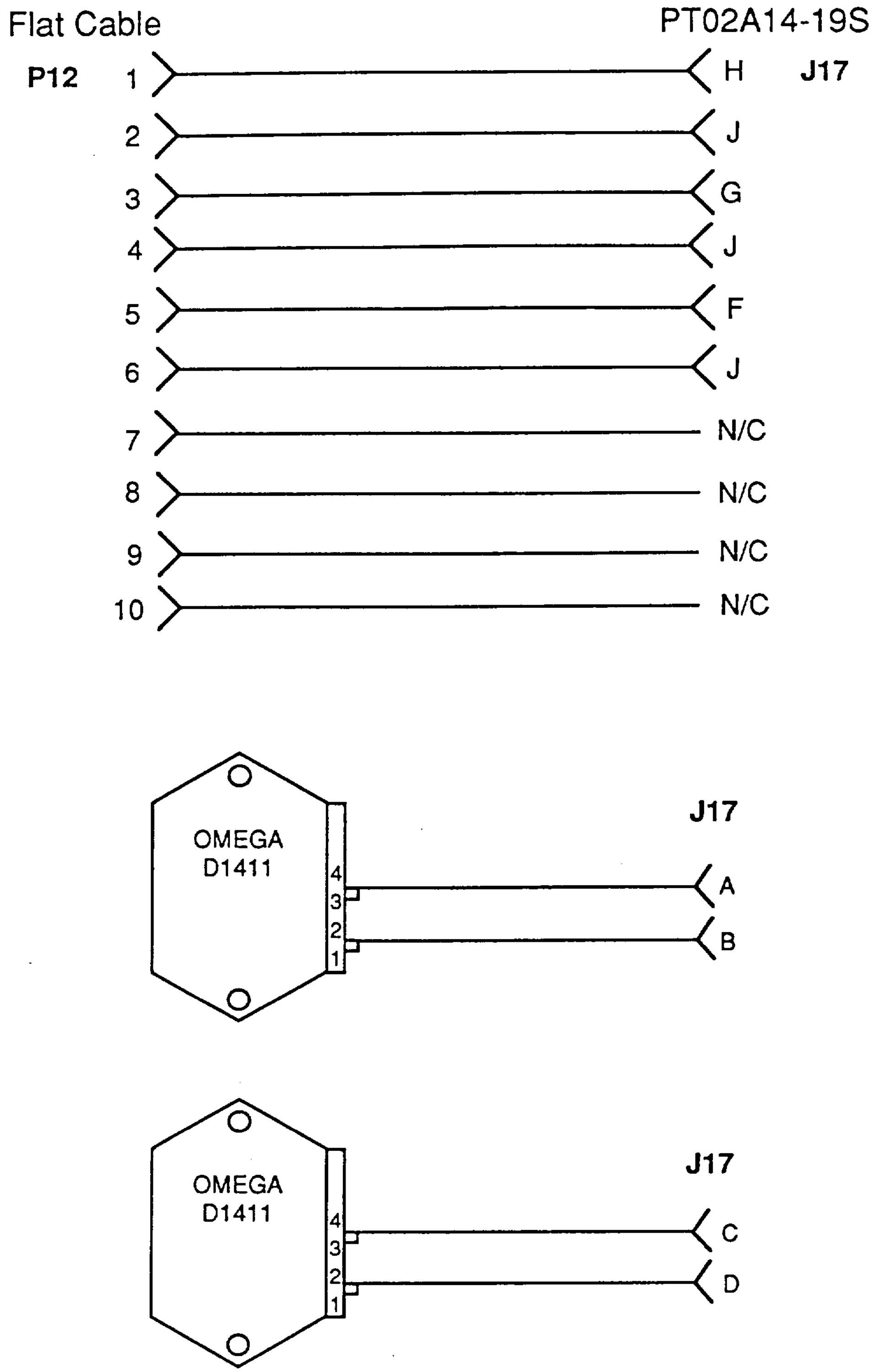
SPECTROMETER CONTROL CABLE



SPECTROMETER MAIN CABLE



TAXI to SPECTROMETER CONTROL CABLE

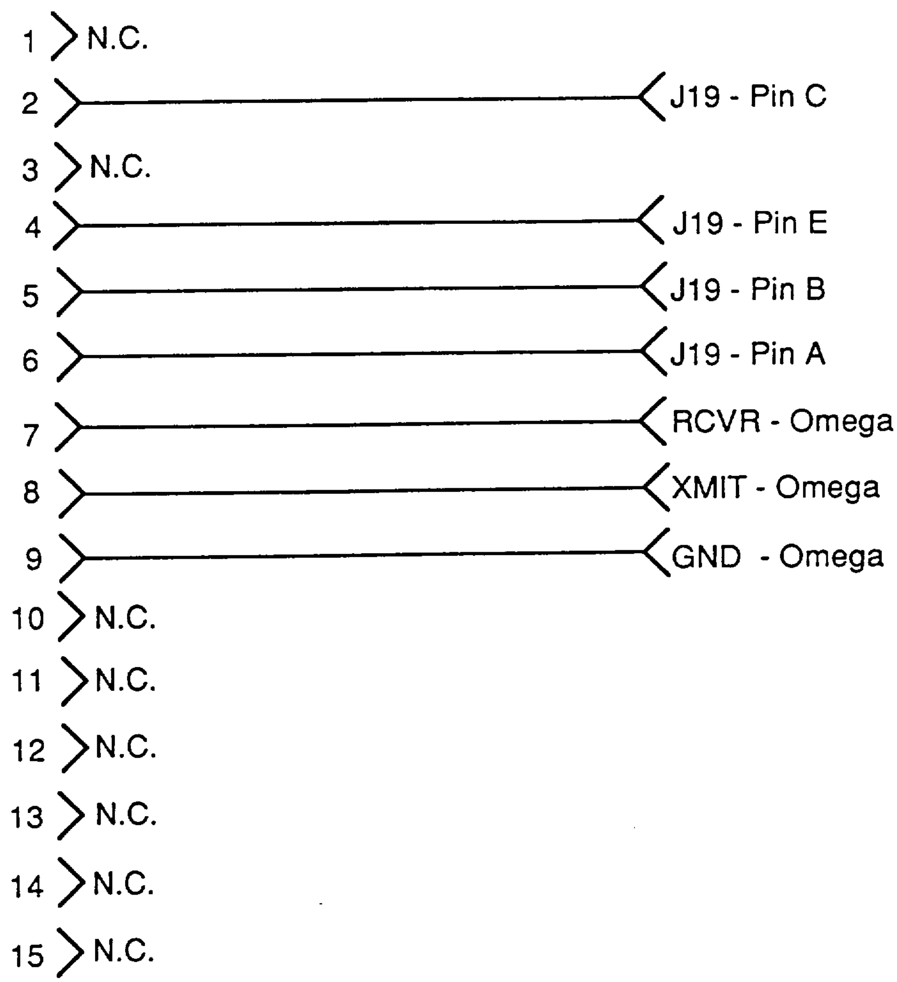


DETECTOR INTERFACE to SPECTROMETER MAIN CABLE

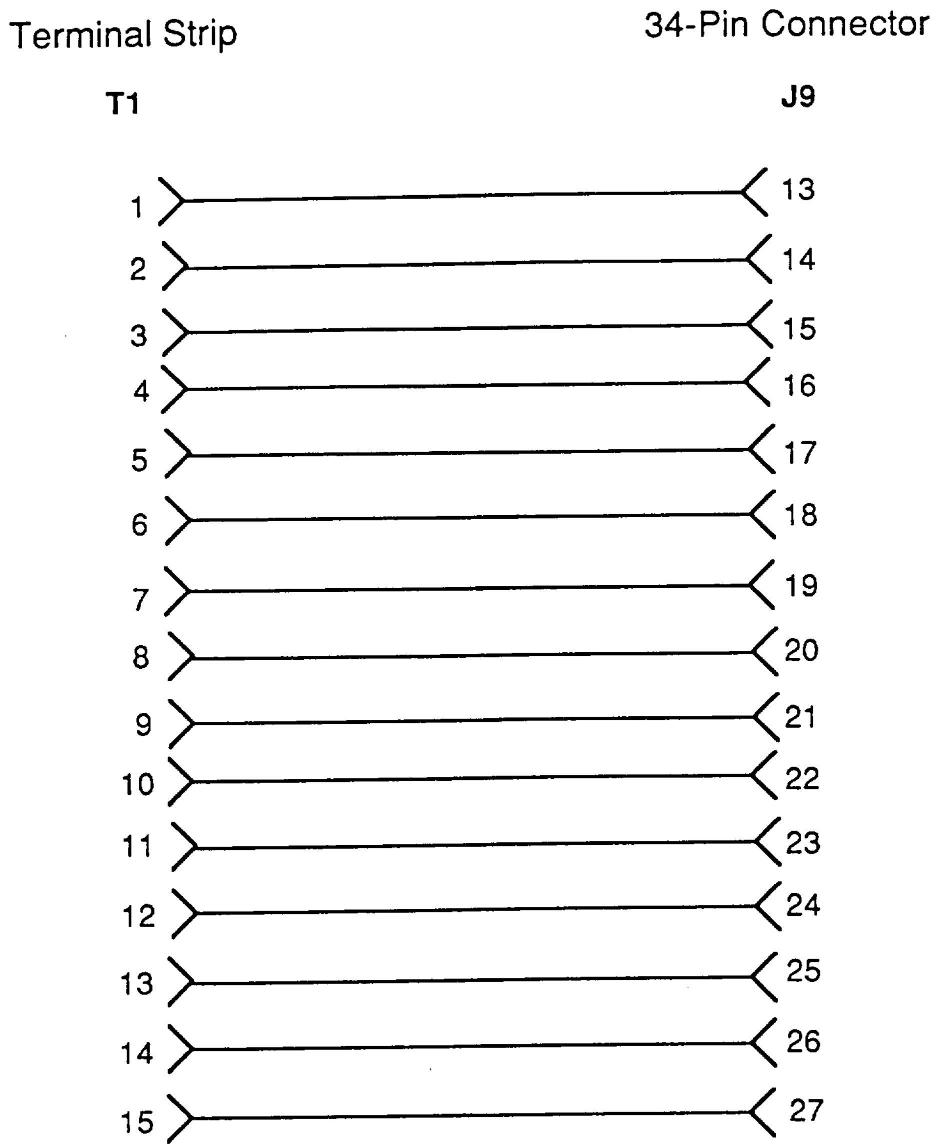
Flat Cable P15	PT02A16-26S J16
1	A
2	B
3	C
4	D
5	E
6	F
7	G
8	H
9	J
10	K
11	L
12	M
13	N
14	P
15	R
16	S
17	T
18	U
19	V
20	W
21	X
22	Y
23	Z
24	a
25	b
26	c

TAXI INTERFACE WIRING

T 1



TAXI INTERFACE BOARD J9 to T1



TAXI INTERFACE to DETECTOR INTERFACE CABLE

Flat Cable P10	Flat Cable P13
1	1
2	2
3	3
4	4
5	5
6	6
7	7
8	8
9	9
10	10
11	11
12	12
13	13
14	14
15	15
16	16
17	17
18	18
19	19
20	20
21	21
22	22
23	23
24	24
25	25
26	26
27	27
28	28
29	29
30	30
31	31
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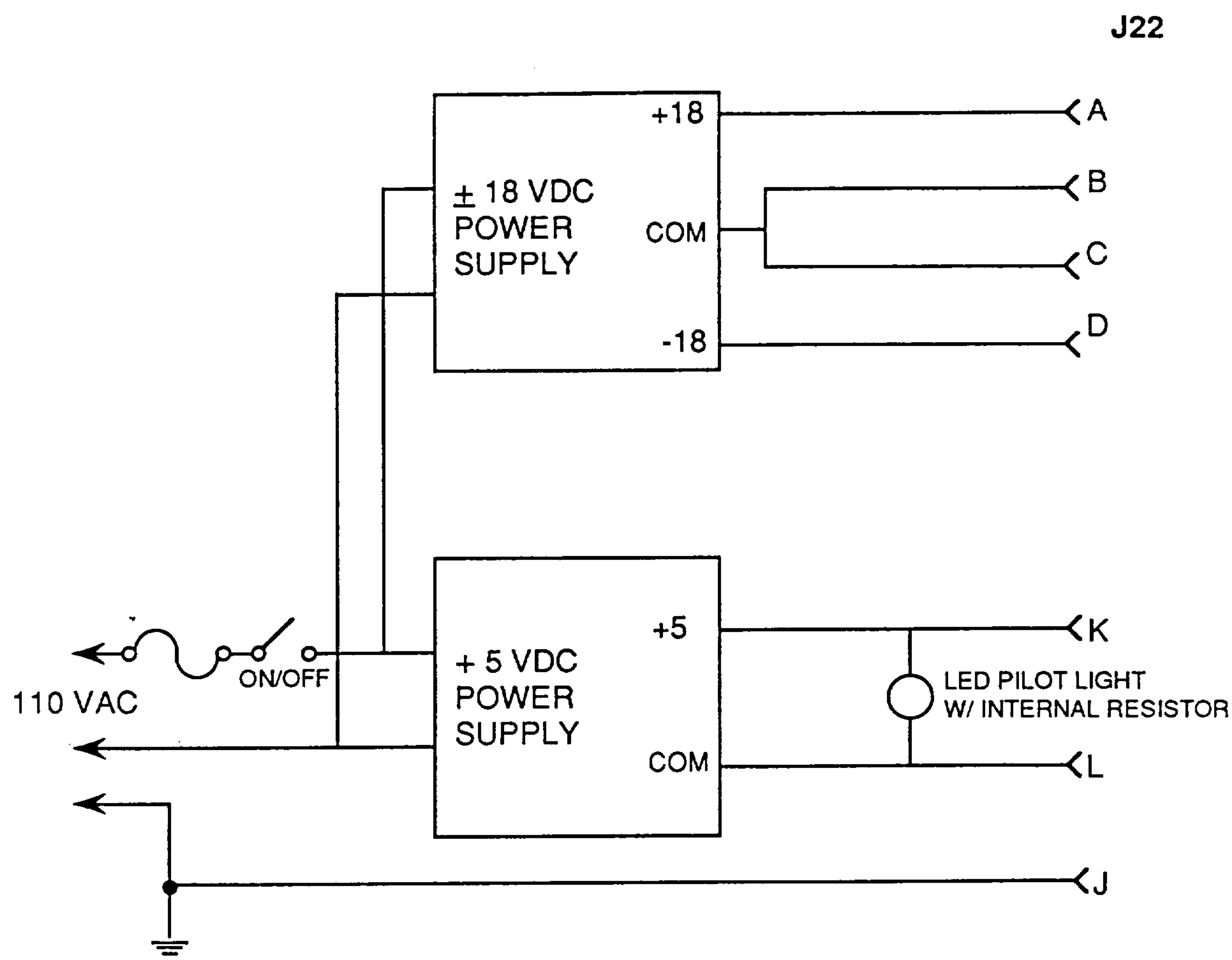
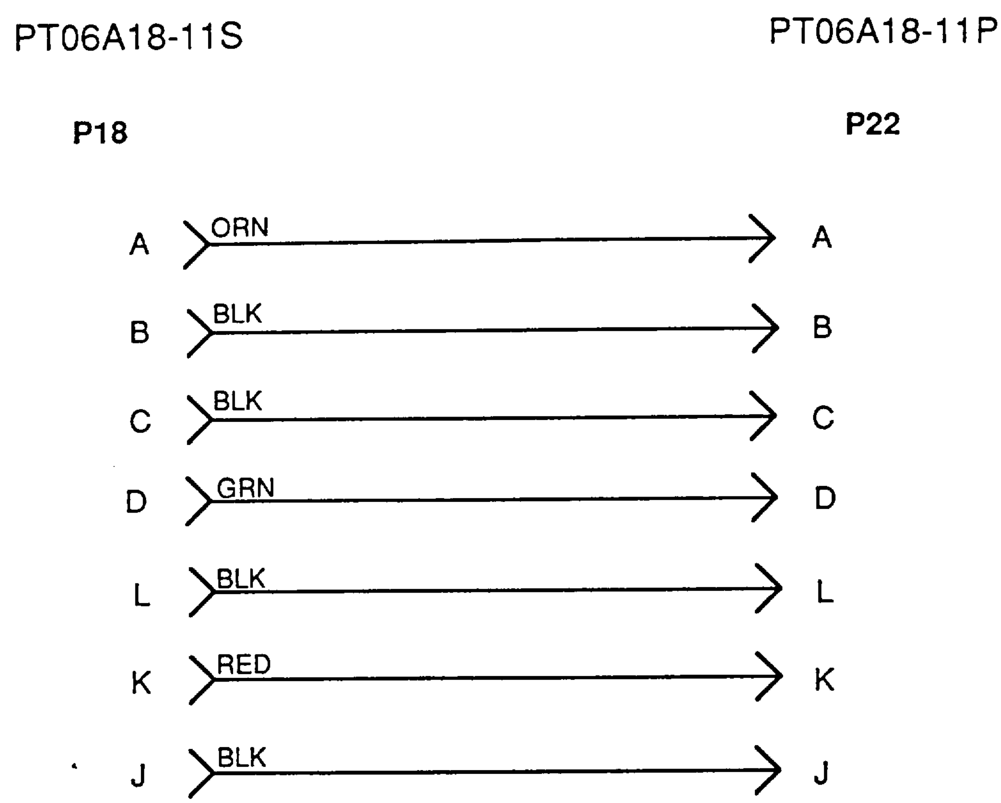
37	37
38	38
39	39
40	40

POWER SUPPLY for INTERFACE ELECTRONICS BOX

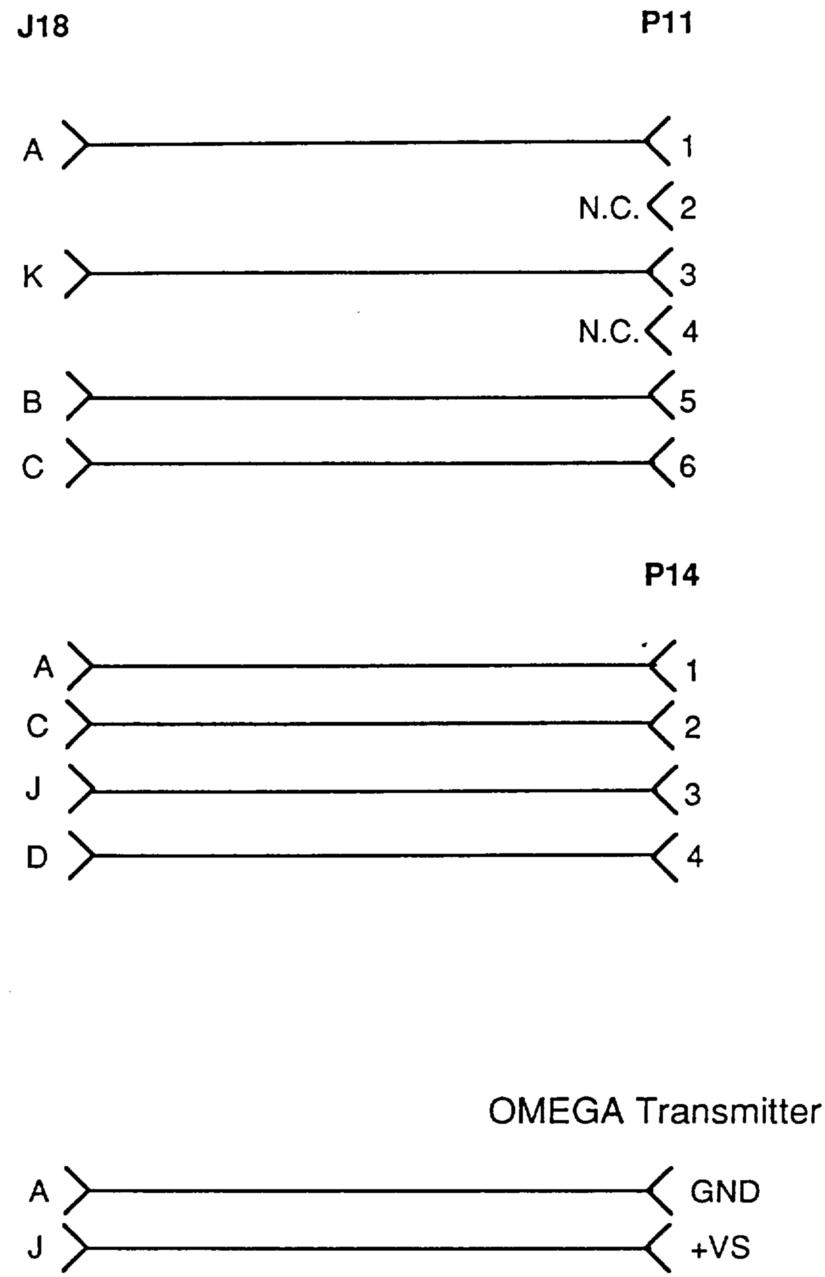


MAIN POWER CABLE

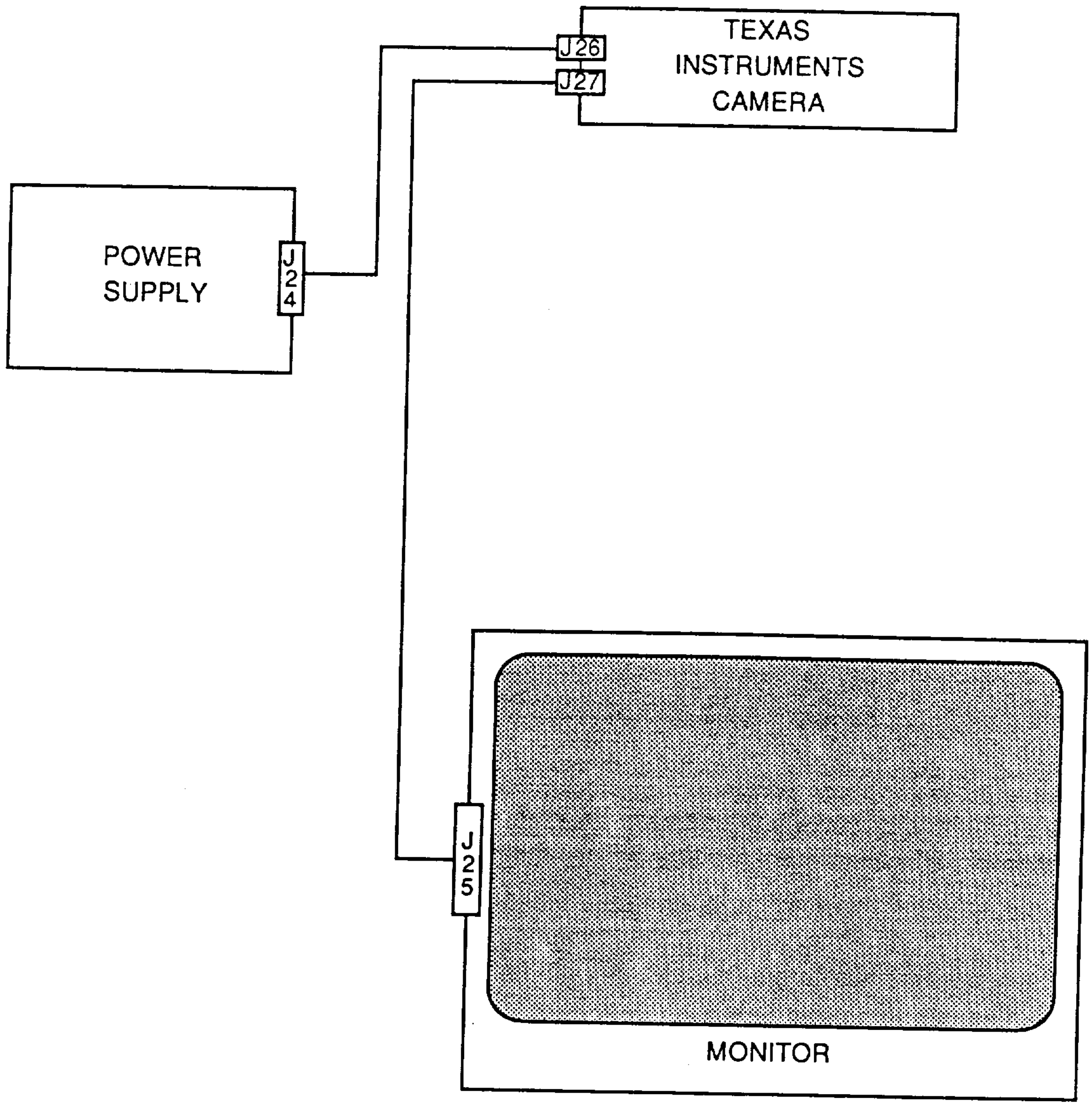


DETECTOR INTERFACE POWER SUPPLY HARNESS

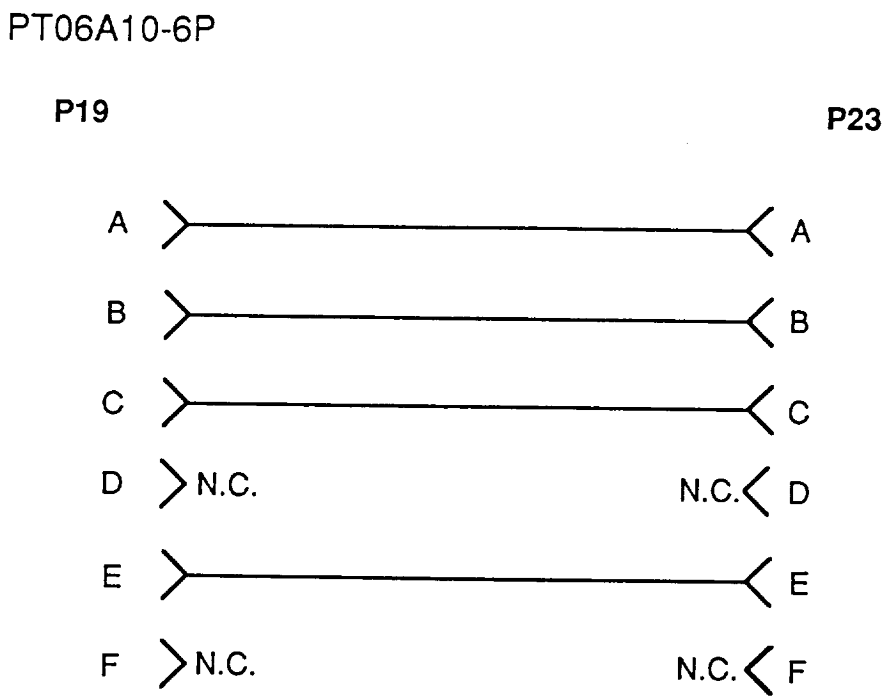
PT02A18-11P



TEXAS INSTRUMENTS CAMERA



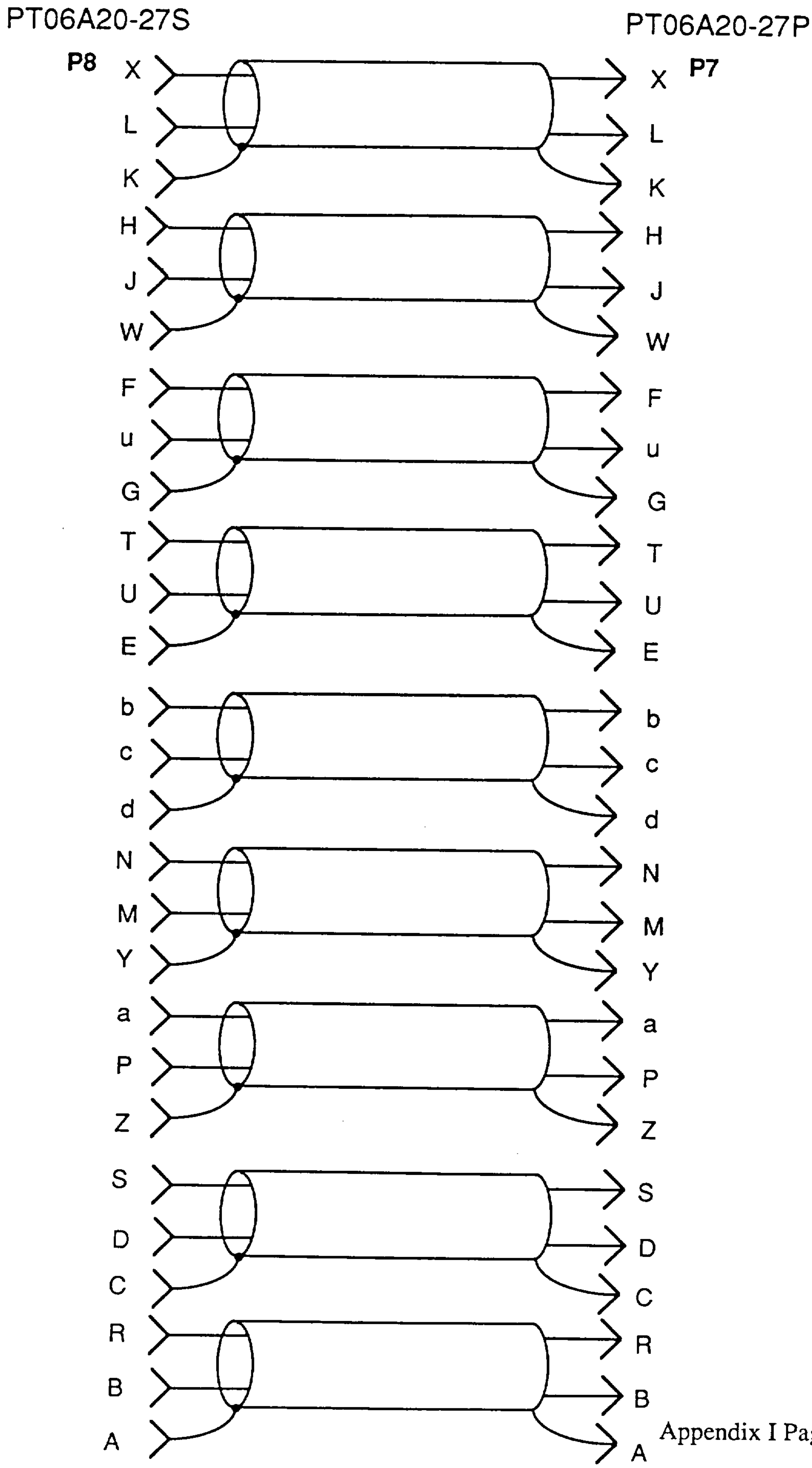
FILTER WHEEL CONTROL CABLE



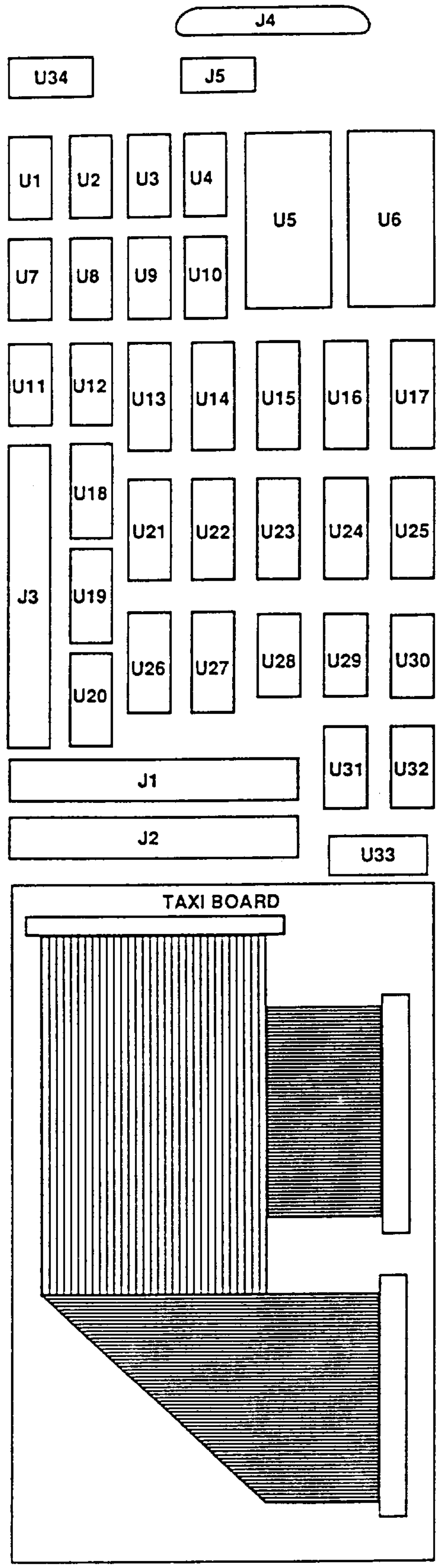
TAXI INTERFACE to MAIN INSTRUMENT CABLE

J9 Flat Cable	J8 PT02A20-27S
1	K
2	L
3	X
4	W
5	J
6	H
7	G
8	V
9	F
10	E
11	U
12	T
13	d
14	c
15	b
16	Y
17	M
18	N
19	Z
20	P
21	a
22	C
23	D
24	S
25	A
26	B
27	R

MAIN INSTRUMENT CABLE



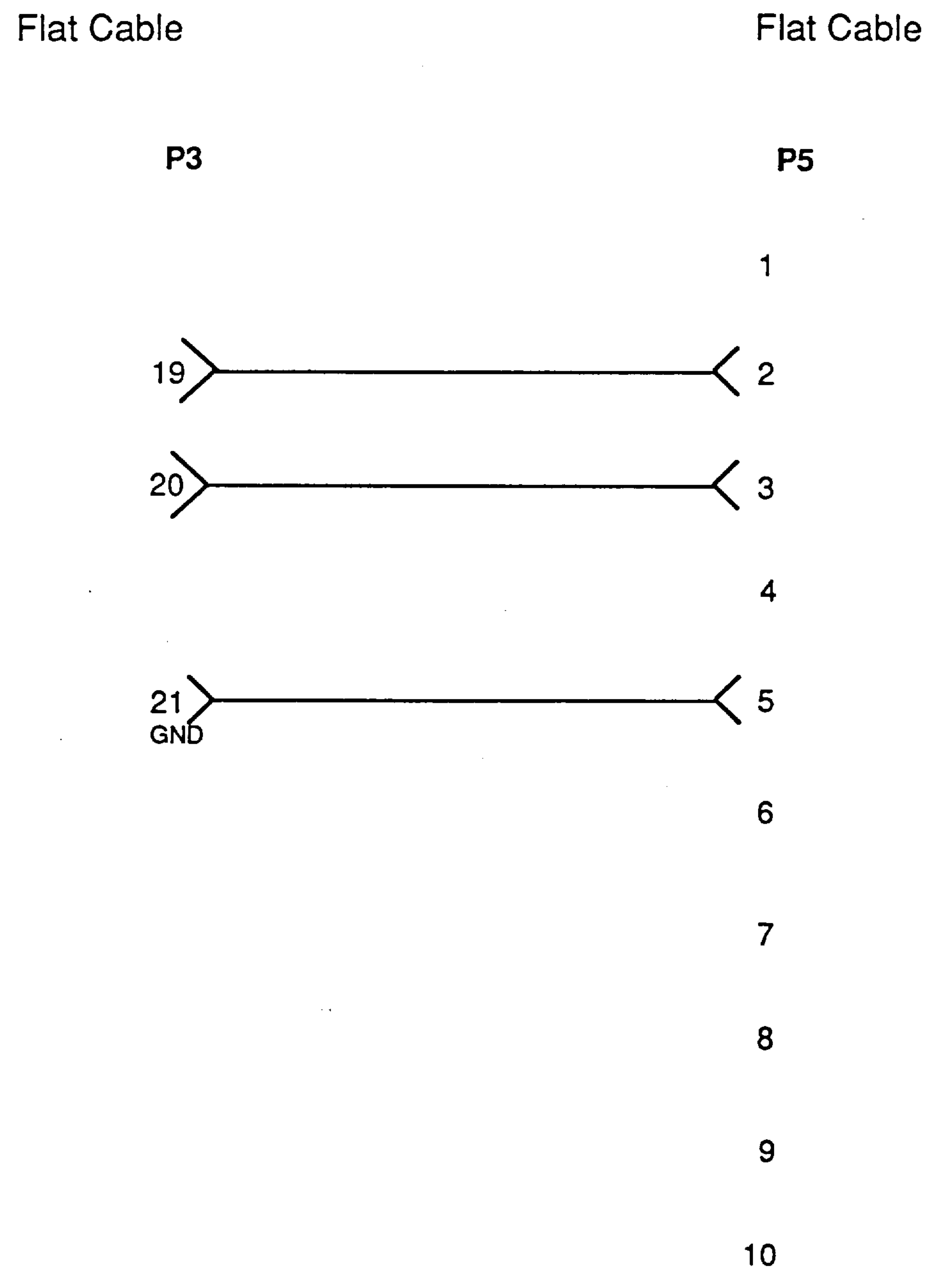
NEW VECTRA BOARD LAYOUT



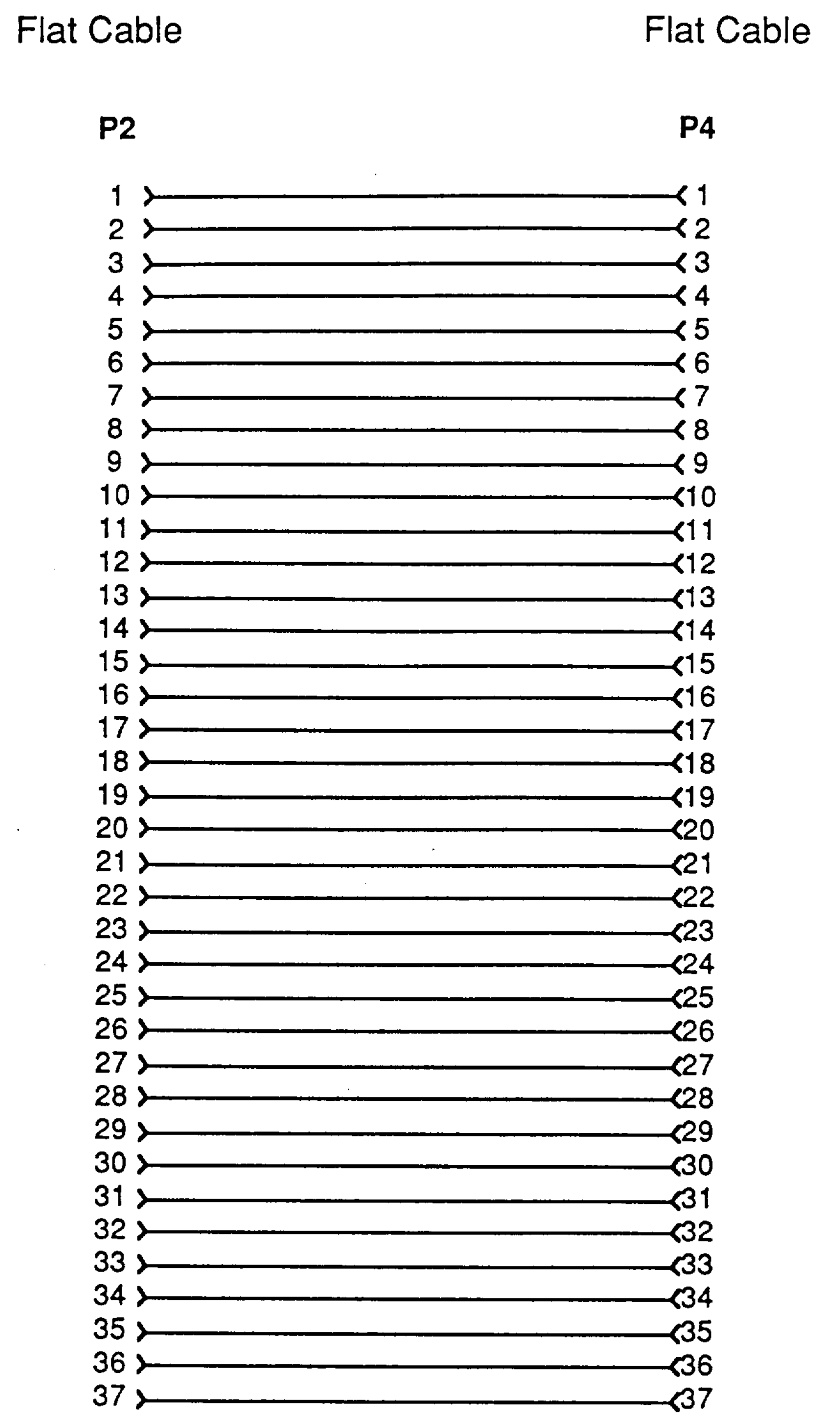
CONTROL INTERFACE to MAIN INSTRUMENT CABLE

Flat Cable P3	PT02A20-27P J7
1	K
2	L
3	X
4	W
5	J
6	H
7	G
8	u
9	F
10	E
11	U
12	T
13	d
14	c
15	b
16	Y
17	M
18	N
19	Z
20	P
21	a
22	C
23	D
24	S
25	A
26	B
27	R

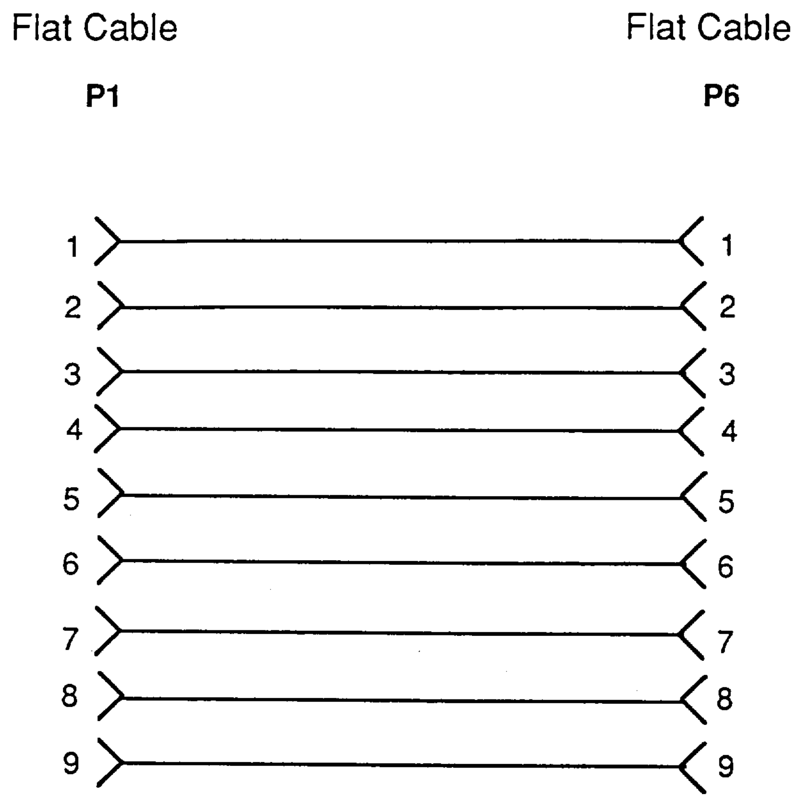
SERIAL CONNECTOR to CONTROL INTERFACE



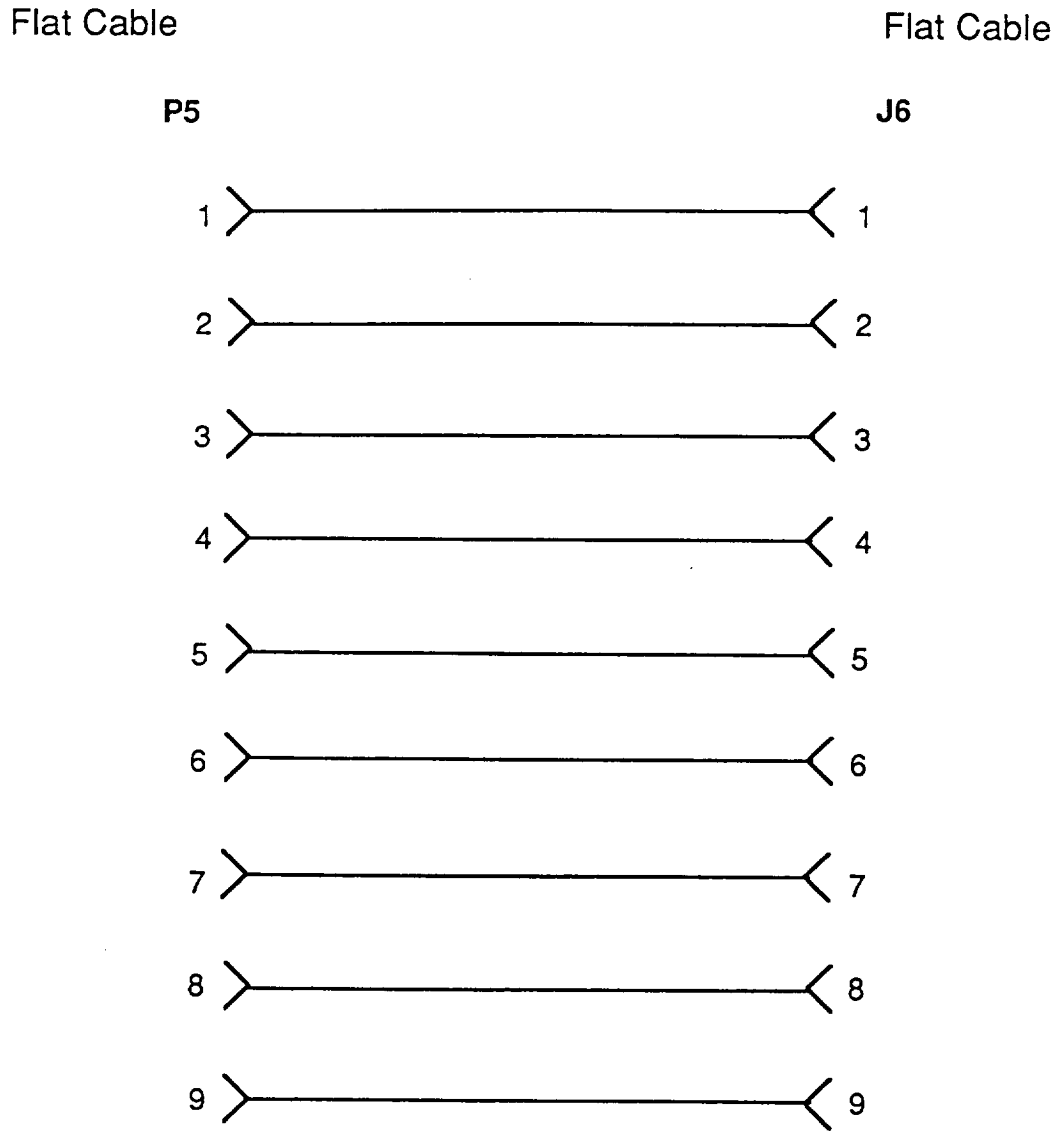
CONTROL INTERFACE to METRABYTE CABLE



COM1 to SERIAL CONNECTOR CABLE



SERIAL INTERFACE



10 No connection

IN321 REV. A

INSTRUCTIONS FOR IBM * AT PLUGBORD (4617 SERIES)

1.0 BOARD DESCRIPTION

The 4617 series plugboards for the IBM AT computer have a .1" x .1" hole pattern for unrestricted component placement. Power and ground buses surround the grid pattern on both the component and solder side of the board for all patterns except the 4617-4 power and ground plane board.

The 4617-4 plugboard allows low inductance power or ground connections to be made at any location on the .1" x .1" hole pattern area with an eyelet, Vector part number T123. Push the eyelet into the hole location to be connected, and solder the eyelet flange to the power or ground foil.

Universal D-subminiature and .1" x .1" patterns are provided on the rear board edge.

A layoutsheet is provided to aid in I.C. and component placement.

A universal bracket is provided for four sizes of I/O connectors or to secure the board into the computer chassis.

2.0 CONNECTOR LOCATION AND NUMBERING

IBM motherboard connector locations are shown in fig. 2-1. Motherboard pin numbers and signal names are shown in fig. 2-2.

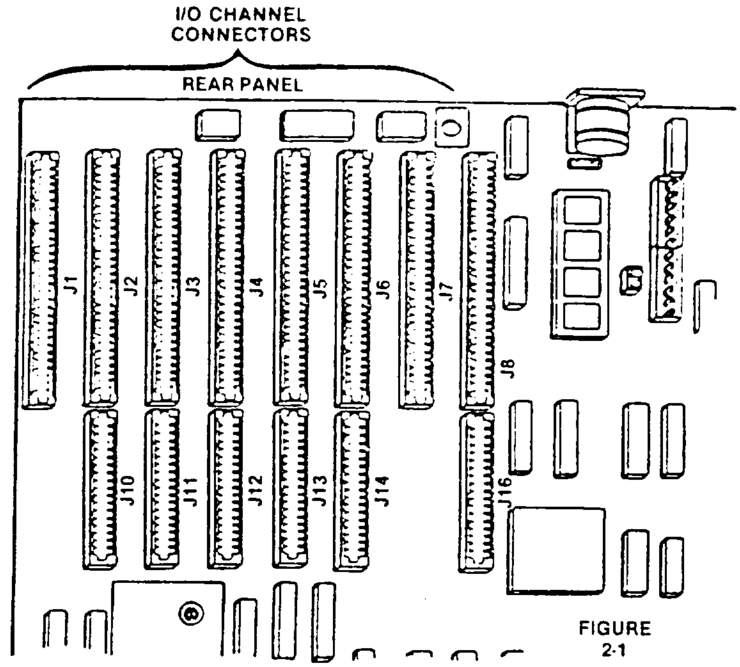


FIGURE 2-1

I/O Pin	Signal Name
A1	-I/O CH CK
A2	SD7
A3	SD6
A4	SD5
A5	SD4
A6	SD3
A7	SD2
A8	SD1
A9	SD0
A10	-I/O CH RDY
A11	AEN
A12	SA19
A13	SA18
A14	SA17
A15	SA16
A16	SA15
A17	SA14
A18	SA13
A19	SA12
A20	SA11
A21	SA10
A22	SA9
A23	SA8
A24	SA7
A25	SA6
A26	SA5
A27	SA4
A28	SA3
A29	SA2
A30	SA1
A31	SA0

I/0 Pin	Signal Name
B1	GND
B2	RESET DRV
B3	+5 Vdc
B4	IRQ 9
B5	-5 Vdc
B6	DRQ2
B7	-12 Vdc
B8	OWS
B9	+12 Vdc
B10	GND
B11	-SMEMW
B12	-SMEMR
B13	-IOW
B14	-IOR
B15	-DACK3
B16	DRQ3
B17	-DACK1
B18	DRQ1
B19	-Refresh
B20	CLK
B21	IRQ7
B22	IRQ6
B23	IRQ5
B24	IRQ4
B25	IRQ3
B26	-DACK2
B27	T/C
B28	BALE
B29	+5 Vdc
B30	OSC
B31	GND

I/O Pin	Signal Name
C1	SBHE
C2	LA23
C3	LA22
C4	LA21
C5	LA20
C6	LA19
C7	LA18
C8	LA17
C9	-MEMR
C10	-MEMW
C11	SD08
C12	SD09
C13	SD10
C14	SD11
C15	SD12
C16	SD13
C17	SD14
C18	SD15

I/O Pin	Signal Name
D1	-MEM CS16
D2	-I/O CS16
D3	IRQ10
D4	IRQ11
D5	IRQ12
D6	IRQ15
D7	IRQ14
D8	-DACK0
D9	DRQ0
D10	-DACK5
D11	DRQ5
D12	-DACK6
D13	DRQ6
D14	-DACK7
D15	DRQ7
D16	+5 Vdc
D17	-MASTER
D18	GND

FIGURE 2-2

3.0 UNIVERSAL BRACKET

A Universal bracket is provided for mounting one of 4 I/O connectors; it can also be used to secure the board without an I/O connector. See fig. 3-1. The D-subminiature 9-pin AMP no. 745112-2; 15-pin AMP no. 745113-2; 25-pin AMP no. 745114-2; or 37-pin AMP no. 745115-2 or equivalent connector may be used if their dimensions match fig. 3-2 to fit the bracket and computer.

FIGURE 3-1

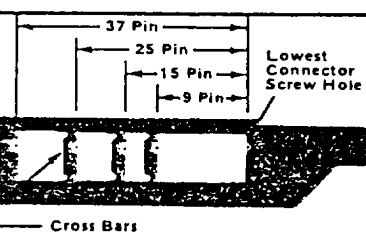
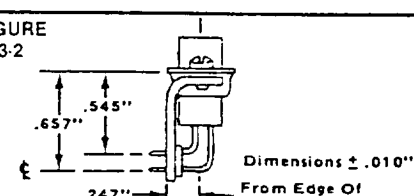


FIGURE 3-2



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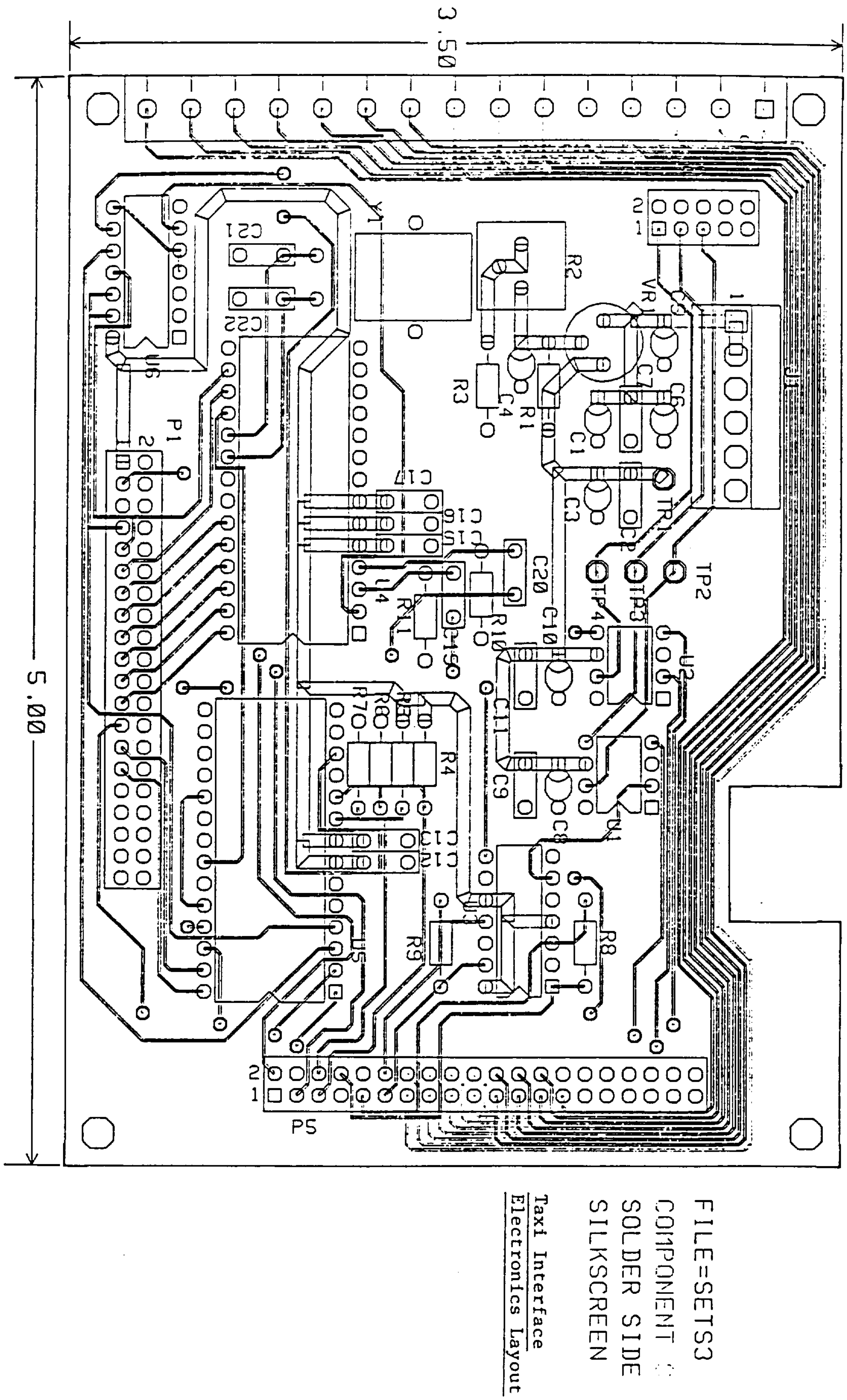
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5.00
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COMPONENT
SOLDER SIDE
SILKSCREEN
Taxi Interface
Electronics Layout
P1
P5
U1
U2
U4
U5
U6
Y1
VR1
TP2
TP3
TP4
R1
R2
R3
R4
R8
R9
R10
R11
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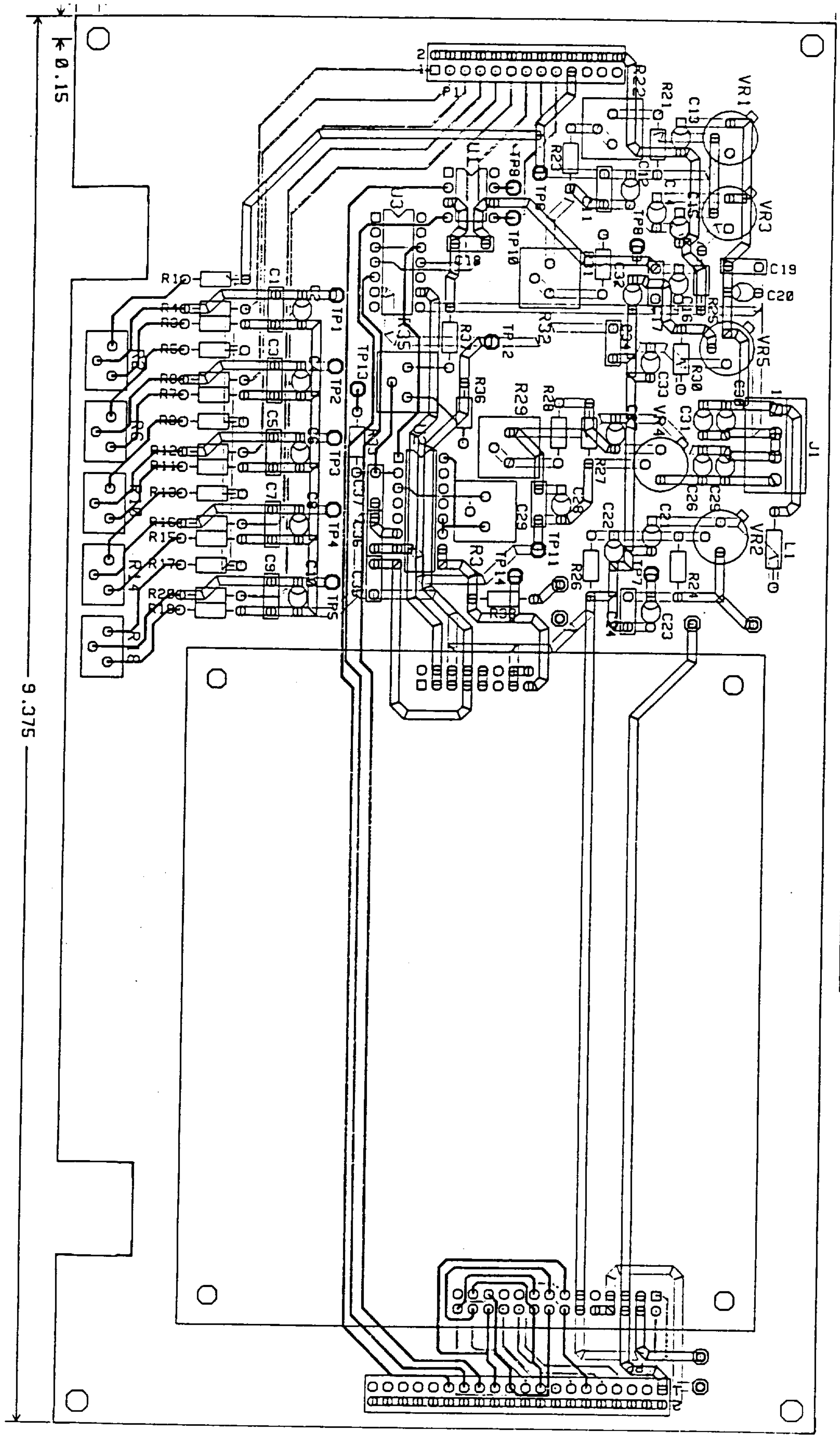
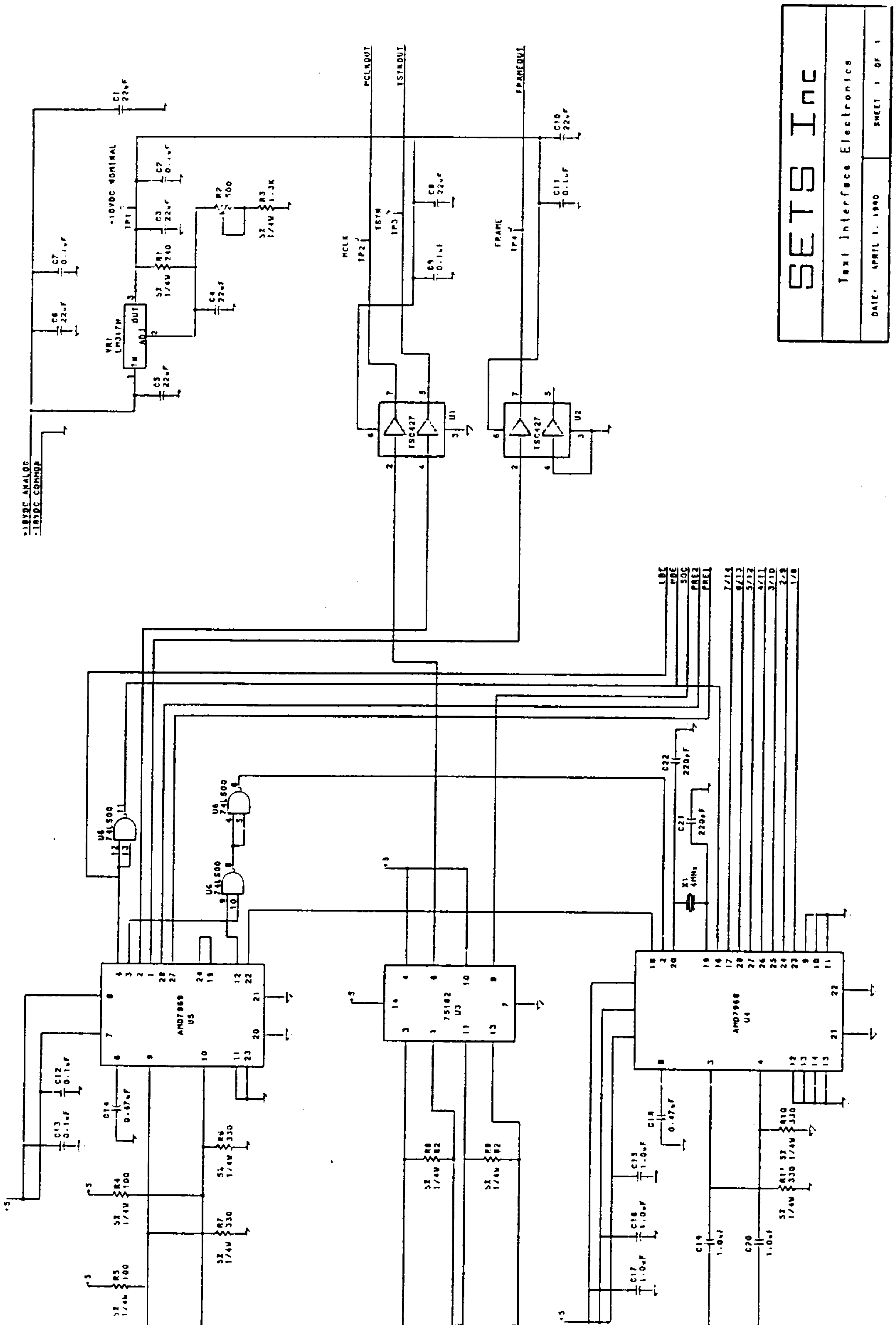
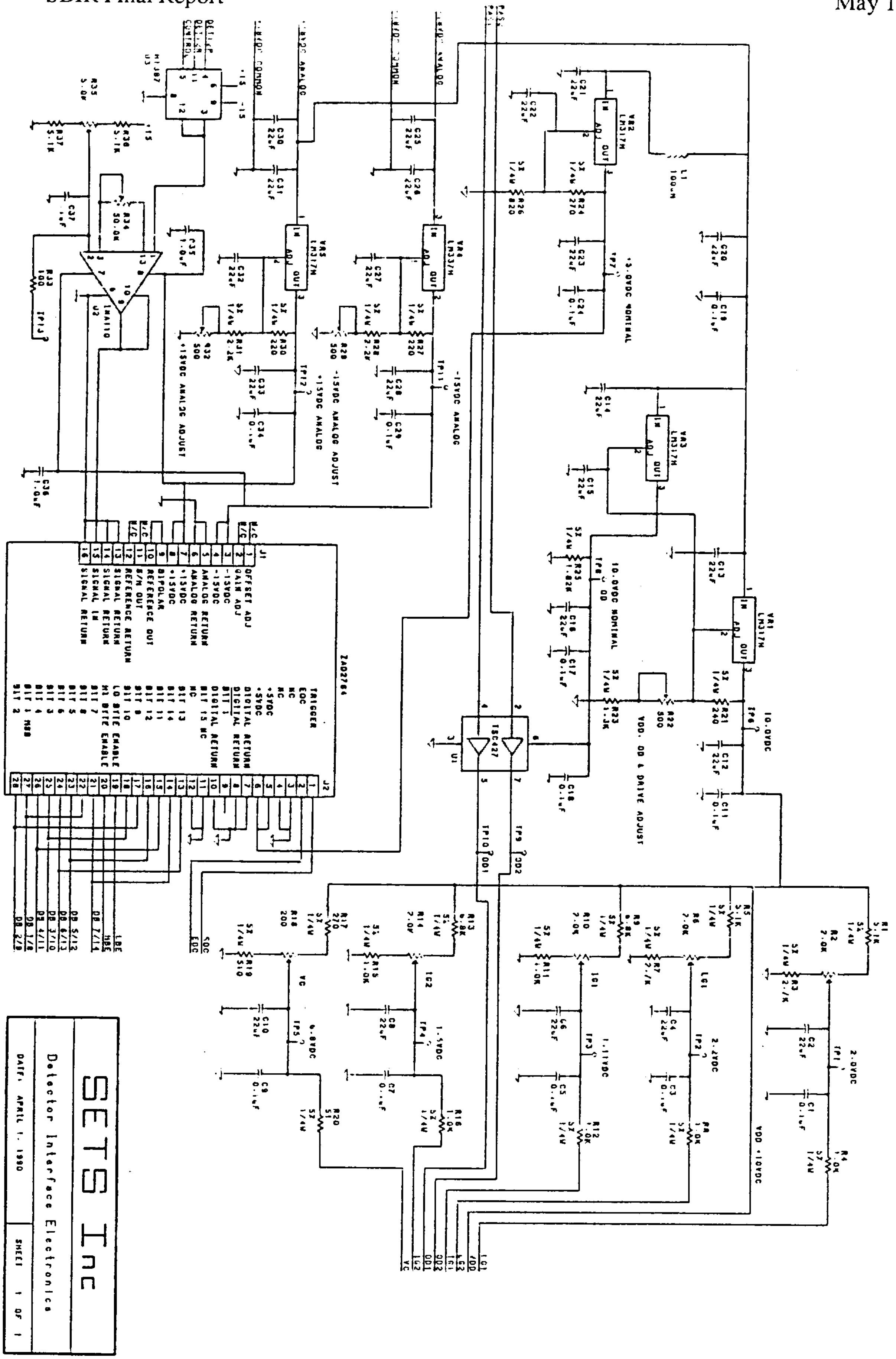
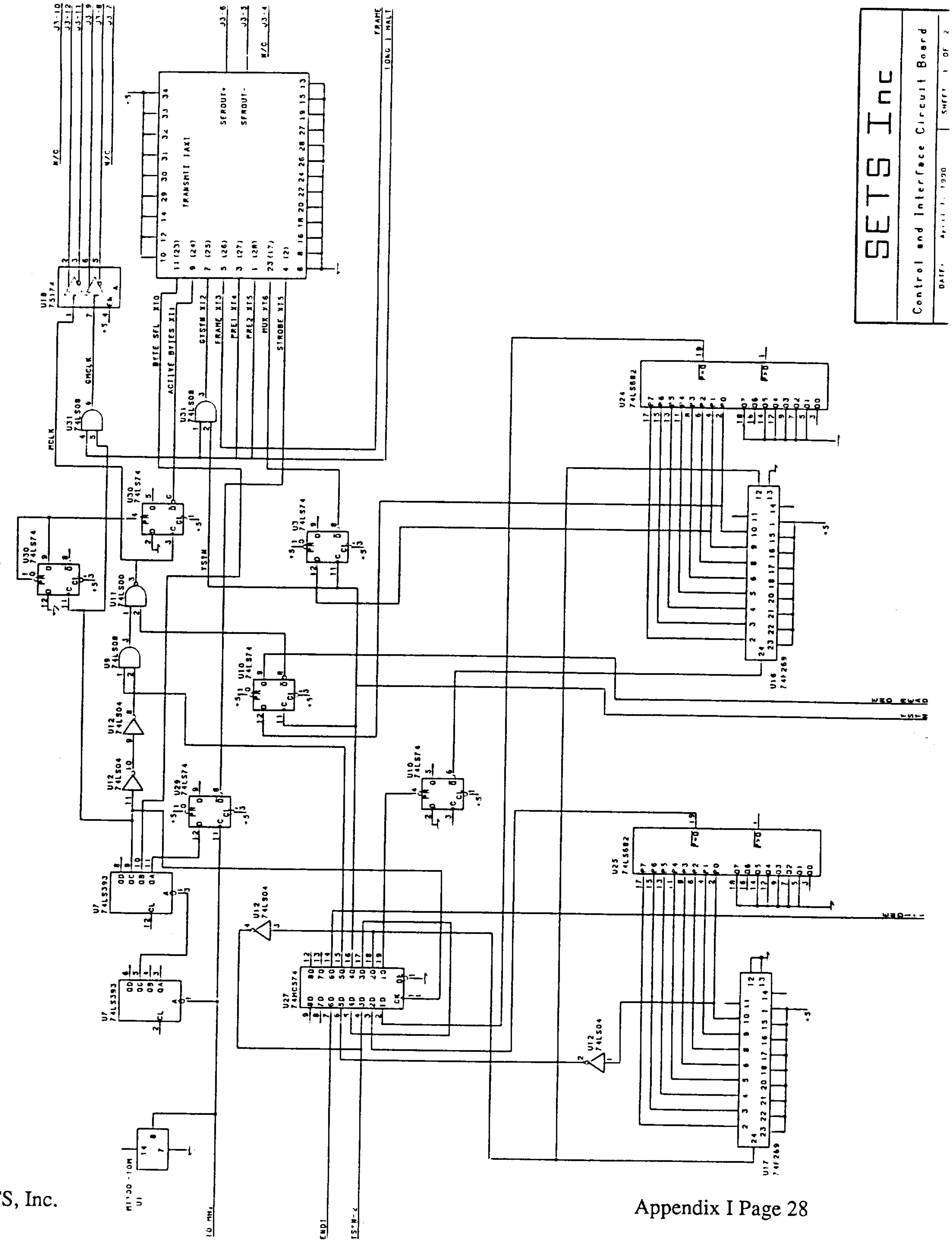
C17
C20
C21
C22

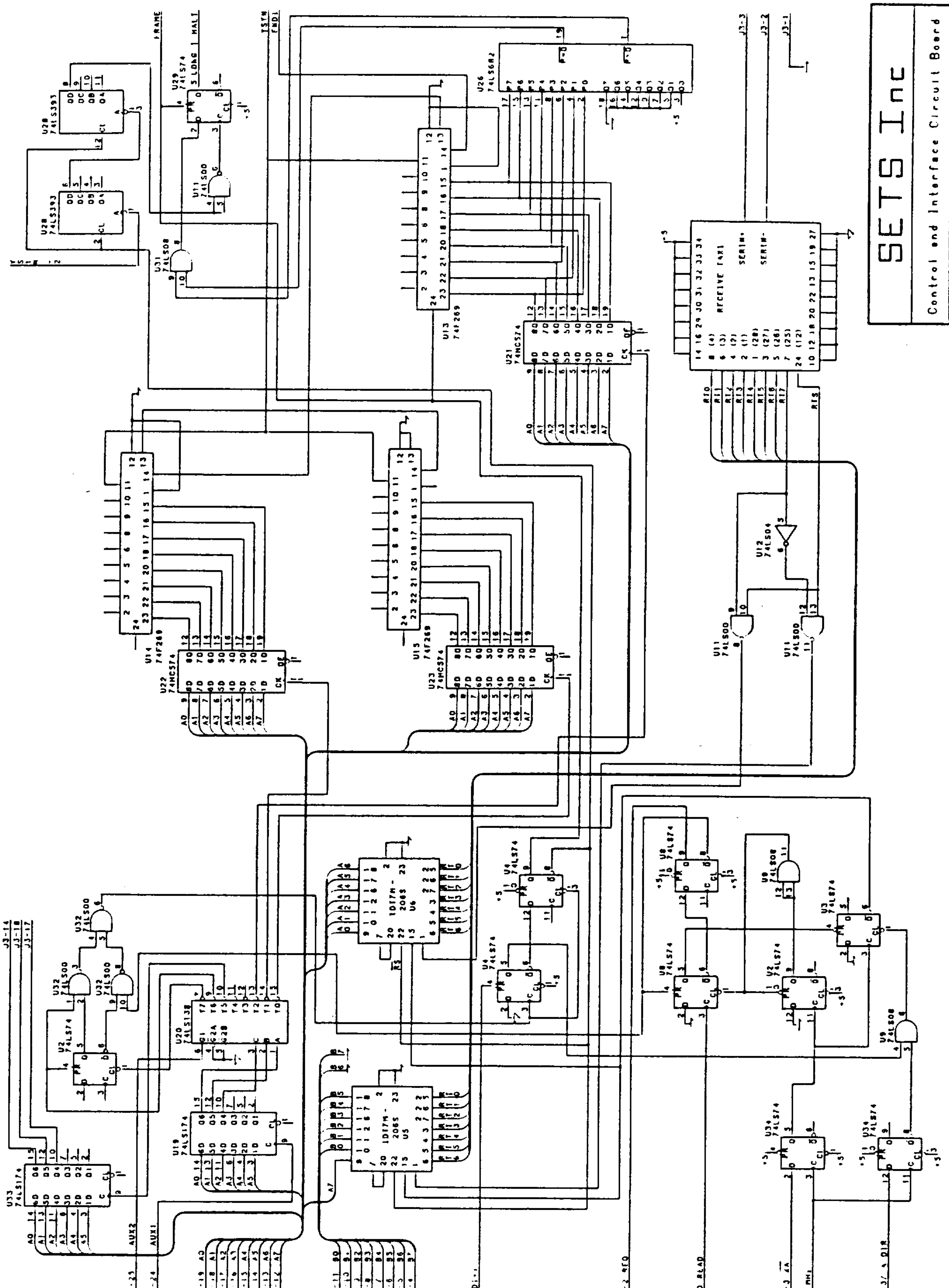


Detector Interface Electronics Layout


SETS Inc
Taxi Interface Electronics
DATE: APRIL 1, 1990
SHEET 1 OF 1


SETS Inc
Detector Interface Electronics
DATE: APRIL 1, 1990
SHEET 1 OF 1


SETS Inc
Control and Interface Circuit Board


SETS Inc
Control and Interface Circuit Board